93 232 35255 / 249

ACTA UNIVERSITATIS SZEGEDIENSIS

PARS CLIMATOLOGICA SCIENTIARUM NATURALIUM

CURAT: G. KOPPÁNY

ACTA CLIMATOLOGICA

TOMUS XXI-XXIII.

FASC. 1—4

Folyóiratok SZEGED

SZEGED (HUNGARIA)

1989.

ACTA UNIVERSITATIS SZEGEDIENSIS

PARS CLIMATOLOGICA SCIENTIARUM NATURALIUM

CURAT: G. KOPPÁNY

ACTA CLIMATOLOGICA

TOMUS XXI-XXIII.

FASC. 1—4

SZEGED (HUNGARIA)

1989.

THE VARIABILITY OF THE TEMPERATURE AND THE WIND DIRECTION AT SZEGED IN VARIOUS LARGE SCALE PATTERN

by

G. Koppany and *A. Kiss*

A hőmérséklet és a szélirány változékonysága Szegeden különböző makroszinoptikus helyzetekben. A szerzők Szeged 20 évi adatsorát (1961-1980) felhasználva megvizsgálták a napi hőmérsékleti anomáliák és a napi maximális széllökések irányának eloszlását a *Péczely-féle*, valamint az *Ambrózy-Bartholy-Gulyás-féle (ABG)* makroszinoptikus típusok szerint rendezett részhalmazokban. Meghatározták a napi hőmérsékleti anomáliák *szórását és Shannon-entrópiáját a teljes populációra, továbbá az említett típusok részhalmazaira.* A napi maximális széllökések irányainak Shannon-entrópiáját hasonló módon kiszámították. Valamennyi feldolgozást a négy évszakra külön végezték el; a kapott statisztikai eredményeket az *I-VIII. táblázatok* foglalják össze. Az ABG-típusok szerint rendezett relatív gyakoriságokat az 1-8. ábrák mutatják be. Az eredmények szerint a típusok többségében mindkét osztályozás csökkenti a napi adatok szórását ill. entrópiáját. Az entrópia csökkenése a Péczely-típusok esetén valamivel kifejezettebb.

The authors investigated the frequency distributions of the daily temerature anomalies and of the direction of the daily maximum gust in the subsets arranged according to the large-scale circulation types classified by *Péczely*, as well as *Ambrózy-Bartholy and Gulyás (ABG)* using a 20-year data series (1961-1980) of Szeged. The standard deviations and *Shannon entropies* of the daily temperature anomalies were calculated for the total population and for the subsets of the above mentioned large scale types. The Shannon entropies of the directions of the daily maximum gusts were determined in the same way. All calculations for the four seasons were made separately, and the results obtained are summarized in Tables I-VIII. The relative frequencies of the temperature and the wind directions in different ABG types are shown in Figs. 1-8. It was found that in the majority of the types both classifications deminish the standarddeviations, as well as Shannon entropies of the daily data. The decrease of entropy is a little more expressed in the case of Péczely types.

Introduction

Attempts at classing circulation processes among types of a finite number have been made in a number of countries. These classings have been realised for diverse space scales, from the synoptic scale to the hemispheric scale. *H.H.LAMB* has taken for this basis the current and pressure conditions predominating above the British Isles *(GIRS* and *KONDRATOVICH*, 1978,p. 294*)*. *P. HESS* and *H. BREZOWSKY*'s (1953) circulation classification is orientated to Central Europe. *B.L. DZERDZEJEWSKY* has classified hemispheric circulation on the basis of the Arctic cold outbreaks *(GIRS* and *KONDRATOVICH*, 1878, pp. 66-67*)*. Especially known has become *G.Y. VANGENHEIM*'s classification, which has classed the circulation of the whole hemisphere among nine main types *(GIRS*, 1974; *GIRS* and *KONDRATOVICH*, 1978, 99. 67-81*)*.

Though these classifications defined the individual patterns as types of finite number, the classifications have been realised on the basis of subjective decisions. For that very reason, a number of researches have striven to characterize circulation, producing an infinity of transitions, by numerical parameters. The various circulation indexes proved to be means suitable for this. *J. NAMIAS* (1947) defined indexes for characterizing the zonal circulation of the Northern Hemisphere, namely for 3 zones of latitude separately, on the basis of the pressure data measured on sea level and at an altitude of 3 km. It is also for measuring the intensity of zonal circulation that *E.N. BLINOVA* has worked out an index *(GIRS* and *KONDRATOVICH*, 1978, pp. 87-88*)*, while it is *A.L. KATS* who has combined the indexes of meridional and zonal circulations *(KOPPANY*, 1986. p.113*)*.

A classification orientated to Hungary was done by *G. PECZELY* (1956, 1957a, 1957b), and 13 types were differentiated by him. He extended the catalogue of the types established for the individual days to the years 1881-1983 (*PECZELY*, 1983). As in the cases of similar classifications usually, the claim of the objective, that is numerical definition has come up in relation to Péczely types, too. By the help of cluster analysis *P. AMBROZY, J. BARTHOLY* and *O. GULYAS* (1984) have worked out a classification depending on the season. For the individual seasons they have defined types of different numbers: for winter 17, for spring 19, for summer 8, and for autumn 15 types. While sea level pressure distribution that *PECZELY*'s classification takes for its basis, and it is a smaller area (about 35-65° N, 10°W-40°E) that he takes into consideration, the ABG classification uses the field of the 500 mb level in a larger area (30-65°N, 40°W-50°E), which spreads over a part of the Atlantic Ocean, too.

One of the practical purposes of classifying circulation types is creating the basis of the conditional climatological investigations, for it is to be expected that the standard deviations of the subsets of weather elements according to types decrease as compared to the standard deviation of the total climatic population. The decrease of standard deviation generally goes with the decrease of uncertainty, which we can measure by the calculation of Shannon entropy. The aim of our investigation is to reveal, by the use of the measured data of Szeged in Southern Hungary, the decrease of the standard deviations and entropies of the data, relating to the subsets of two different classifications, Péczely and ABG types.

Data Base and Method

For the processing with 20-year length period (1961-1980) of the daily measurements of the Szeged meteorological station were used, namely the daily mean values of the temperature, and the directions of the maximum gusts. The latter departs, on the one hand, from an earlier processing of *PECZELY*'s (1957b), in which he had taken into consideration the wind directions measured at 0600 GMT; on the other hand, from *K. TAR*'s (1985) investigation, in which the author had used the hourly anemometries. As *J. SZALMA* (1977) has revealed, 90 % of the hourly wind speeds occurs in the range 0-5 ms^{-1}, and only 10 % of them exceeds the of 5 ms^{-1} force. Weak air motions, in turn, are more influenced by local factors, and in them the baric situation of synoptic scale is less reflected. Stronger wind data, on the contrary, conform to the large-scale pressure conditions somewhat better. Therefore, it seems more expedient to sort the directions of the maximum wind gusts according to the macrosynoptic types.

The catalogue of the ABG classification for the years 1949-1980 (*AMBROZY, BARTHOLY* and *GULYAS*, 1983), and the Péczely catalogue for the years 1881-1983 are available. In Szeged, instrumental observations, with repeated transfers of the weather station, have been going on since 1871 (*SINDELY*, 1985). The station has been functioning on its present spot since 1961; therefore, for our investigation have been chosen the 20 years between 1961-1980.

While processing the daily mean values of temperature, first we determined the daily normal values concerning the period of the years 1961-1980, then the deviations from these, that is the daily anomalies. We determined the standard deviations of the daily temperature anomalies, and the relative frequencies of the latter ones calculated for classes of a breadth of 1°C, and with the help of the relative frequencies we determined the Shannon entropy, on the one hand, for the whole population, and, on the other hand, for the subsets arranged according to the Péczely and ABG-types, as well as we also determined the averages of the temperature anomalies for the individual subsets. The above calculations were done for the four seasons separately. The decreases in the standard deviation and the Shannon entropies signify the becoming arranged of the data within the macrosynoptic situations.

While processing the directions of the daily maximum wind gusts, we determined their relative frequencies; furthermore, we calculated the Shannon entropy, for the whole population (E_T), and for the subsets of the individual types (E_i).

The Shannon entropy, serves for the measuring of uncertainty, and for its determination we used the following, generally accepted formula:

$$E = \sum_i p_i \log_2 1/p_i \qquad \text{[bit]}$$

Here p_i is the relative frequency of the i-th event.

In the case of the temperature we used one-degree spaces between the values, and we classed the directions of the maximum gusts among 16 categories.

We compared the order of the data in the subsets of the Peczely and the ABG types season by season by means of a computer.

Results

In the course of the investigation we were looking for answers to the following questions:

1. Do the standard deviation and the entropy of the daily temperature anomalies decrease in the partial populations of the individual macrosynoptic situations in comparison with the total population; and if so, with which types is this decrease the greatest? 2. Does the entropy of the directions of the maximum wind gusts decrease in the partial populations in comparison with the entropy of the totel population? 3. With which classification does the entropies'average weighted according to frequencies of the types, decrease more strongly, that is to say which of the two typifyings gives a greater information gain?

In their two previous papers the authors had examined the first two questions in detail (*KOPPANY* and *KISS*, 1985, 1987). In these two papers of theirs, they had limited their investigations to the Péczely types only. They had found that the entropies of the temperature and wind direction data classified according to the Péczely types decreased in comparison with that of the total population. In the case of the temperature, the decrease of entropy is the greatest in the situations of northern and western direction, and in the central cyclonal situation; the arrangement of the temperature data according to the Péczely types is the strongest in winter and summer, and the weakest in spring. In the case of the wind directions, the entropy mainly decreases in types *mCc*, *AB*, *CMc*, *Ae*, *Aw*, *AF* and *C*, in the central anticyclonal situation (*A*), however, it increases in comparison with the total population. Of the seasons, it is in winter and autumn that the entropy decreases the most strongly.

In the present investigation, the authors partly sum up a few of their more important results got for the Péczely types, partly complete them with their recent researches carried out for the ABG types. For it is doubtless that the comparison of the synoptic climatological valuations of the two kinds of typifying can command interest.

Tables I to IV sum up for the four seasons the statistical results got for the order of the daily temperature anomalies. In spring, of the

Péczely types, it is only in the situation *An* that the entropy does not decrease, and it is in the situations *An* and *A* that the standard deviation increases in a small degree.

In spring the entropy decreases in a larger or smaller degree in each of the 19 ABG types; the standard deviation, however, increases somewhat with six types (*Table I*).

In summer the entropy decreases in each of the Péczely types; the standard deviation, with the exception of the situation *As*, also decreases in all situations. In summer the number of the ABG types is only 8; with 4 types of these the standard deviation of the temperature does not decrease, the decrease of the entropy is slight (*Table II*).

In autumn it is in three of the Péczely types that the standard deviation does not decrease; the entropy, however, with the exception of *CMw*, decreases with all types. With 5 of the 15 ABG types the standard deviation increases a little; with 3 of these, the entropy also increases (*Table III*).

In winter it is in only one Péczely and four ABG types that the standard deviation of the temperature does not decrease; the entropy, however, decreases in all types (*Table IV*).

It deserves attention that *in spring and winter*, when the number of the ABG types is the greatest (19 and 17 respectively), the weighted average of the entropy decrease is the greatest: 0.209 and 0.297 bits respectively; while *in summer*, when the number of the ABG types is only 8, the weighted average of the entropy decrease is the smallest: 0.12 bit. The number of the Péczely types is 13 in each season, the entropy decrease changes less from one season to another: it oscillates between 0.261 and 0.338 bits.

The relative frequencies of the daily temperature anomalies classified according to the ABG types are illustrated by *Figs. 1–4*.

The entropies of the *directions of the maximum wind gusts* calculated for the macrosynoptic types and the whole population, are summed up for the four seasons by *Tables V to VIII*.

In spring, of the Péczely types, only in the situations *A* does the entropy not decrease, and of the 19 ABG types, in only one is there no entropy decrease (*Table V*).

In summer, of the Péczely types, again only in the situation *A* does the entropy not decrease, and ones of the 8 ABG types, in two (*Table VI*).

In autumn there is a larger or smaller entropy decrease in each of the 15 ABG types; of the Péczely types, there is none in the situation *A* (*Table VII*). As the authors had pointed out in their previous papers, the air current is weaker than the average in Péczely's situation *A*; therefore, it is understandable that the wind directions do not become arranged in the central anticyclonal situation.

In winter the entropy decreases in all Péczely and ABG types (*Table VIII*).

The weighted average of the entropy decrease is, in the case of the ABG types, the greatest *in winter and autumn*: 0.254 and 0.228 bits respectively, and the smallest *in summer* (0.075 bits), when the number of the types is also the smallest. In the case of the Péczely types, the entropies of the wind directions decrease the most considerably *in winter and autumn*: by 0.426 and 0.416 bits respectively, while *in spring and summer* by only 0.291 and 0.311 bits respectively. The seasonal differences in the decreases of the entropies of the wind directions, similarly to those of the temperature, are considerably greater with the ABG types than with the Péczely types.

The relative frequencies of the directions of the maximum wind gusts in the whole populations and in the populations arranged according to the ABG types are illustrated, relating to the four seasons, in *Figs 5–8*. Of the 19 spring types, the types *1*, *6*, *8*, *13* and *16* which, with a remarkable frequency of the wind directions *SE* and *S*, deserve attention; then, again, types *3*, *5*, *11*, *14* and *17*, with the accumulation of the wind directions *NW* and *N* (*Fig* 5).

In summer it is the frequency of the wind directions *NW* and *N* that are characteristic of types *1*, *2*, *3*, *5*, *6* and *8* of the 8 ABG types; the high frequency of the wind directions contrary to these, however, does not occur in any of the types (*Fig. 6*).

In autumn, of the 15 ABG types, nos. *2*, *5*, *13* and *14* can be characterized by the prevalence of the wind directions *NW* and *N*, while types *3*, *4*, *6*, *12* and *15* by that of the wind directions *SE* and *SSE* (*Fig.* 7).

In winter, of the 17 types, nos. *1*, *5*, *6*, *8*, *9* and *17* excel by the high frequency of the wind directions *SSE* and *SE*, types *2*, *7*, *11*, *12* and *13* by that of the wind directions *NW* and *N* (*Fig.* 8).

Although, with the exception of the summer, a considerable part of the ABG types determined for the individual seasons can be divided into two groups; characteristic of the one of which is the prevalence of the wind directions *SE* and *S*, of the other one that of the wind directions *NW* and *N*, in these types, the contours of the 500 mb level, are only in partial accordance with the most frequent wind directions received from the surface anemometries.

Conclusions

The investigation arranged the anomalies of the daily mean temperatures, and the directions of the maximum wind gusts measured at Szeged, for macrosynoptic types determined on the basis of two classifications different from each other. Both classifications have advantages and disadvantages.

The advantages of Péczely's classification are as follows: 1. that it is based on the analysis of the surface pressure field, which is in a closer connection with the weather, and 2. that it is orientated to Hungary. Its disadvantages are the following: 1. the determination of the types is carried out visually, 2. so it is not free from subjective mistakes.

The advantage of the ABG classification is that for determining the types it uses an objective method worked out well mathematically, the cluster analysis.Its disadvantages are as follows: 1. that it is based on the 500 mb surface referring to a larger area, and 2. that thus its types can less be brought into connection with the weather in Hungary. Despite the disadvantages, the majority of the types obtained by the two classifications decrease the entropies of the temperature and wind data measured at Szeged.

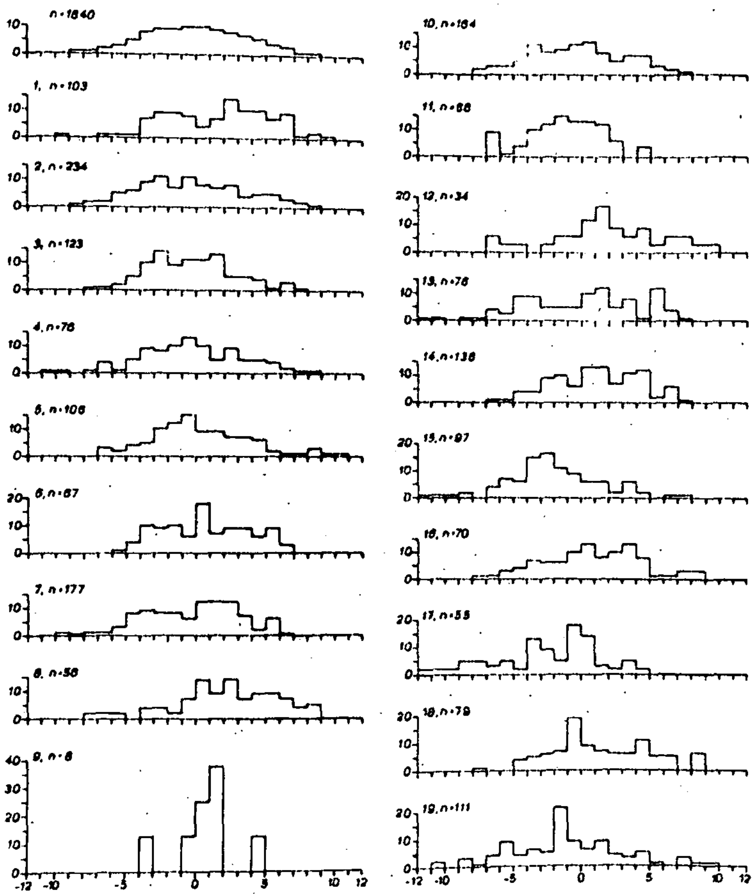


Fig 1 Distribution of relative frequencies of daily temperature anomalies in total population and in ABG-types at Szeged, in spring; n = number of cases

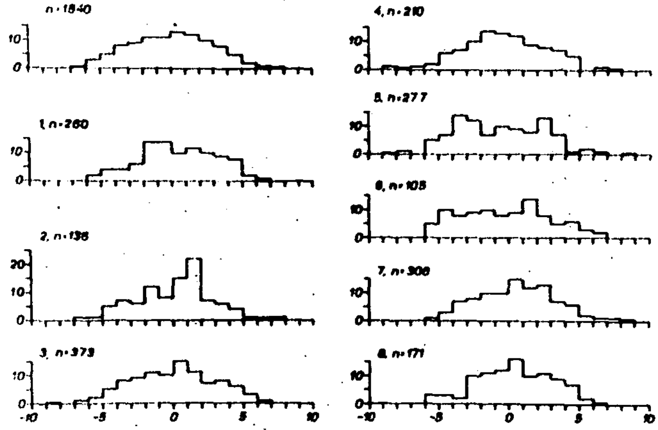


Fig. 2 Distribution of relative frequencies of daily temperature anomalies in total population and in ABG-types at Szeged, in summer; n = number of cases

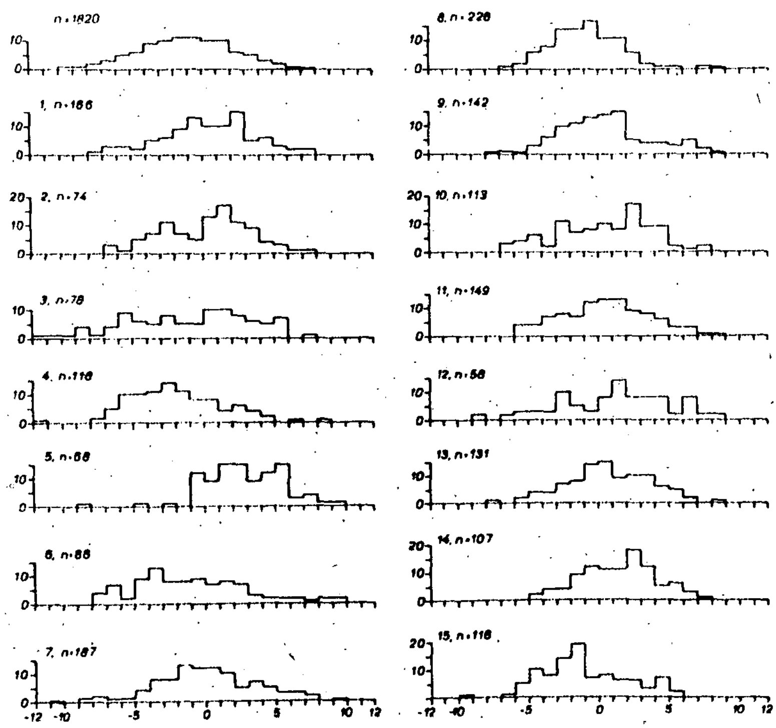


Fig. 3 The same as in Fig. 2, but in autumn

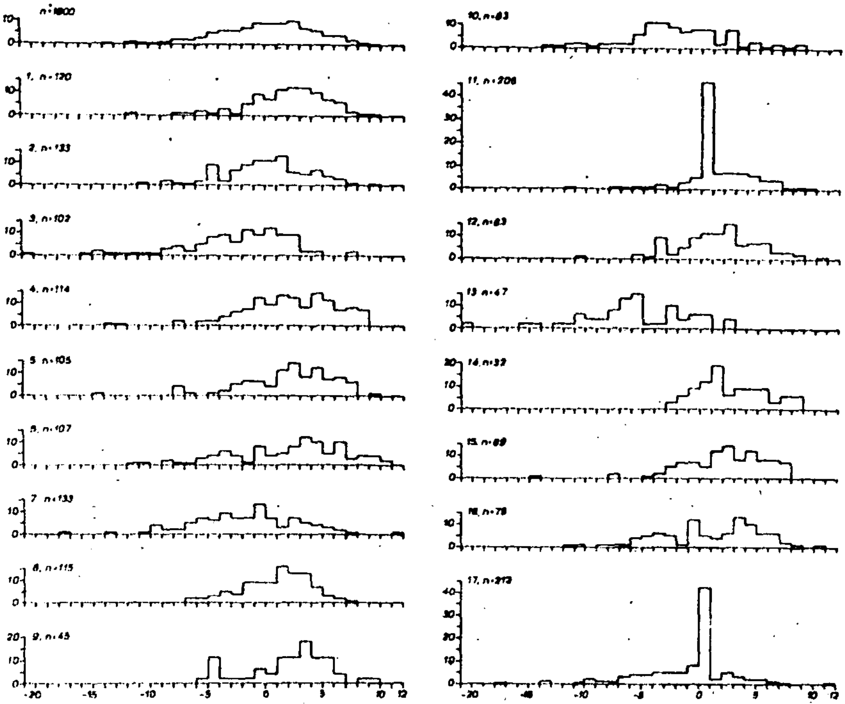


Fig. 4 Distribution of relative frequencies of daily temperatur anomalies in total population and in ABG-types in winter, at Szeged; n = number of cases

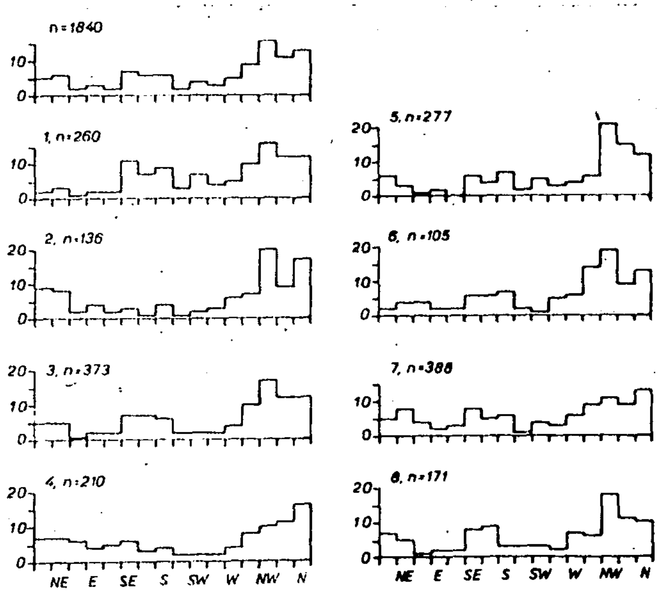


Fig. 6 Relative frequencies of directions of daily maximum gust in total population and in ABG-types at Szeged, in summer; n = number of cases

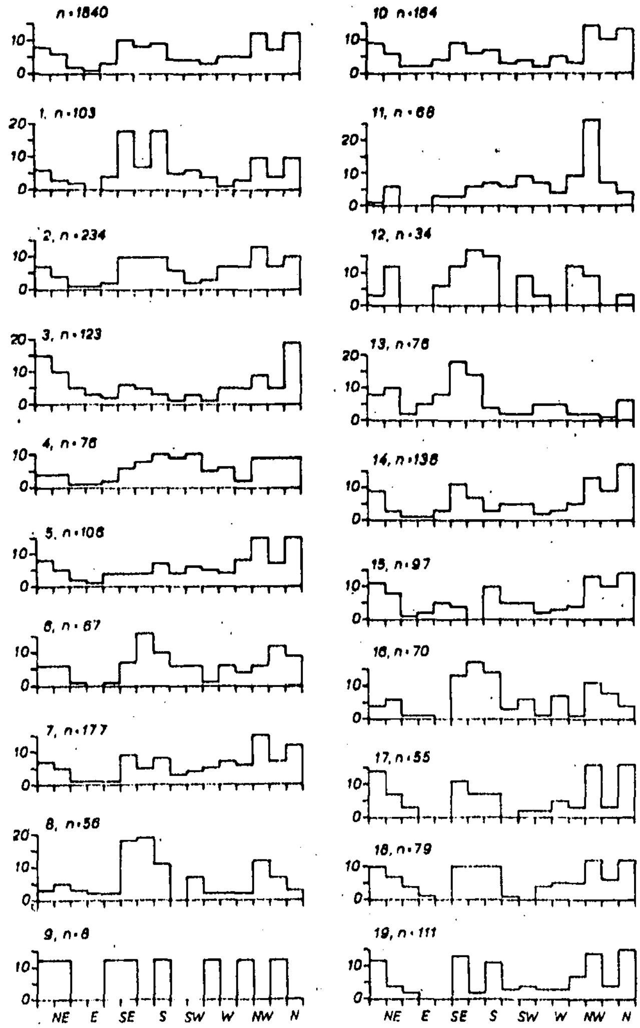


Fig. 5 Relative frequencies of directions of daily maximum gust in total population and in ABG-types at Szeged, in spring; n = number of cases

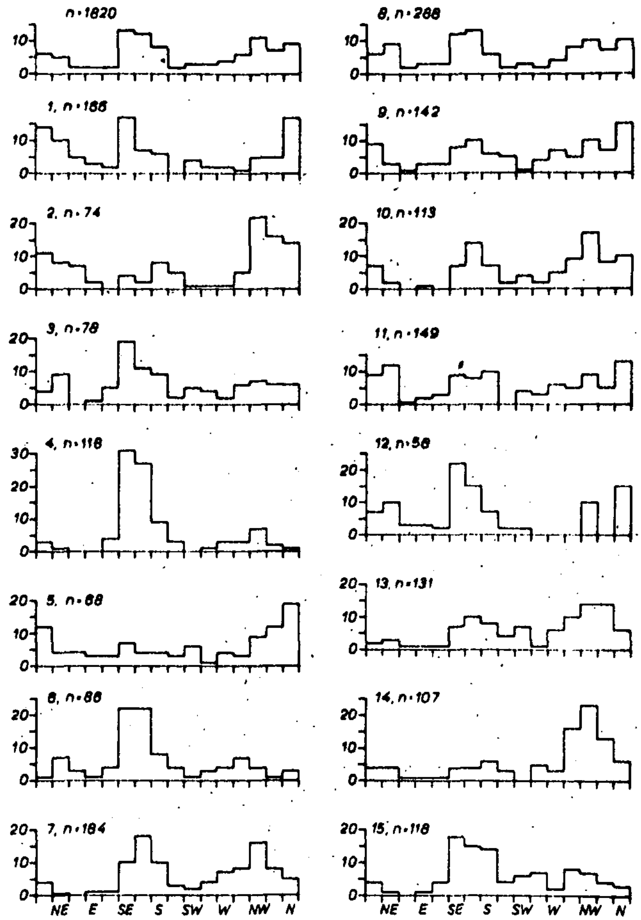


Fig. 7 Relative frequencies of directions of daily maximum gust in total population and in ABG-types at Szeged, in autumn; n = number of cases

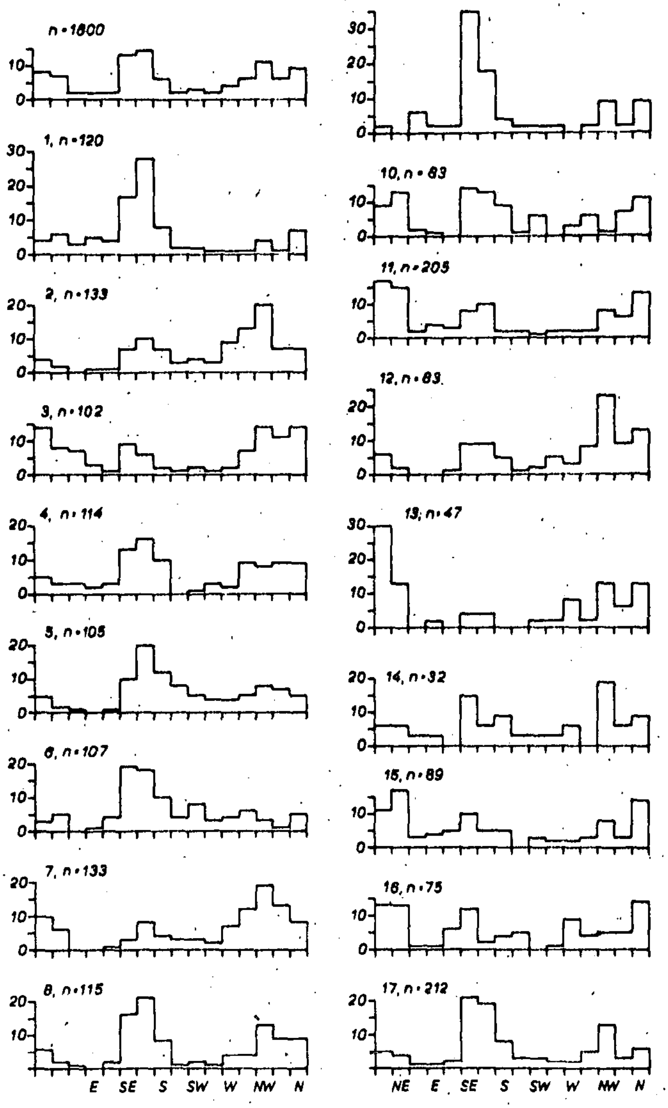


Fig. 8 Relative frequencies of directions of daily maximum gust in total population and in ABG-types at Szeged, in winter; n = number of cases

Table 1

Standard deviations and entropies of the daily temperature anomalies of the spring season at Szeged (1961-1980) in the total population as well as in the subsets arranged according to the Peczely and the ABG macrosynoptic types.
N = number of cases, S = standard deviation, °C, S_T = S of the total population, S_i = S of the subsets, E = entropy, bit, E_T =E of the total population, E_i = E of the subsets

	N	S	S_i/S_T	E	$E_T - E_i$	Average, °C
Total population	1840	3.71	-----	3.921	-----	0.00
			Peczely types			
mCc	118	3.16	0.852	3.570	0.351	-1.71
AB	119	2.97	0.801	3.440	0.481	-2.05
CMc	95	3.18	0.857	3.645	0.276	-2.62
mCw	244	3.29	0.887	3.690	0.231	+2.02
Ae	208	3.12	0.841	3.583	0.338	+2.57
CMw	188	3.53	0.951	3.732	0.189	+0.63
zC	98	3.44	0.927	3.716	0.205	+0.92
Aw	256	3.12	0.841	3.585	0.336	-0.85
As	52	2.90	0.782	3.346	0.575	+2.06
An	237	3.86	1.040	3.926	-0.005	-0.73
AF	86	3.20	0.863	3.605	0.316	-2.00
A	101	3.76	1.013	3.814	0.107	-0.34
C	38	2.88	0.776	3.379	0.542	-1.45
Average of the values ($E_T - E_i$)					0.303	
Average weighted according to frequency Peczely types					0.261	
			ABG types			
1	103	3.58	0.965	3.757	0.164	+1.58
2	234	3.78	1.019	3.895	0.026	-0.36
3	123	3.09	0.833	3.602	0.319	-0.45
4	76	3.89	1.049	3.887	0.034	-0.32
5	106	3.56	0.960	3.733	0.188	+0.47
6	67	3.11	0.838	3.580	0.341	+0.42
7	177	3.48	0.938	3.707	0.214	-0.37
8	56	3.69	0.995	3.708	0.213	+2.29
9	8	2.35	0.633	2.156	1.765	+0.81
10	164	3.46	0.933	3.761	0.160	-0.31
11	68	2.78	0.749	3.279	0.642	+0.78
12	34	4.01	1.081	3.763	0.158	+1.85
13	76	4.39	1.183	3.888	0.033	-0.17
14	136	3.17	0.854	3.586	0.335	+0.87
15	97	3.47	0.935	3.663	0.258	-2.06
16	70	3.56	0.960	3.762	0.159	+0.81
17	55	3.79	1.022	3.680	0.253	-2.51
18	79	3.62	0.976	3.607	0.314	+1.34
19	111	4.01	1.081	3.782	0.139	-1.29
Average of the values ($E_T - E_i$)					0.301	
Average weighted according to frequency ABG types					0.209	

Table II

Standard deviations and entropies of the daily temperature anomalies of the summer season at Szeged (1961-1980) in the total population as well as in the subsets arranged according to the Peczely and the ABG macrosynoptic types.
N = number of cases, S = standard deviation, °C, S_T = S of the total population, S_i = S of the subsets, E = entropy, bit, E_T = E of the total population, E_i = E of the subsets

	N	S	S_i/S_T	E	$E_T - E_i$	Average, °C
Total population	1840	2.96	-----	3.647	-----	0.00
			Peczely types			
mCc	154	2.47	0.834	3.353	0.294	-2.15
AB	133	2.83	0.956	3.450	0.197	-1.62
CMc	53	2.70	0.912	3.200	0.447	-2.65
mCw	156	2.26	0.764	3.181	0.466	+1.10
Ae	147	2.05	0.693	3.073	0.574	+2.82
CMw	74	2.82	0.953	3.362	0.285	-0.54
zC	89	2.53	0.855	3.237	0.410	-0.57
Aw	419	2.75	0.929	3.447	0.200	-0.92
As	29	3.02	1.020	3.411	0.236	+2.26
An	261	2.46	0.831	3.342	0.305	+1.40
AF	91	2.49	0.841	3.213	0.434	-0.74
A	207	2.41	0.814	3.251	0.396	+1.14
C	27	2.91	0.983	3.207	0.440	-1.03
Average of the values ($E_T - E_i$)					0.360	
Average weighted according to frequency Peczely types					0.333	
			ABG types			
1	260	2.76	0.932	3.458	0.189	+0.52
2	136	2.69	0.909	3.421	0.226	+0.06
3	373	3.05	1.030	3.638	0.009	-0.09
4	210	2.92	0.986	3.532	0.115	-0.46
5	277	3.06	1.034	3.545	0.102	-0.76
6	105	3.11	1.051	3.550	0.097	-0.36
7	308	2.96	1.000	3.547	0.100	+0.57
8	171	2.66	0.899	3.394	0.253	+0.33
Average of the values ($E_T - E_i$)					0.301	
Average weighted according to frequency ABG types					0.209	

Table III

Standard deviations and entropies of the daily temperature anomalies of the autumn season at Szeged (1961-1980) in the total population as well as in the subsets arranged according to the Peczely and the ABG macrosynoptic types.
N = number of cases, S = standard deviation, °C, S_T = S of the total population, S_i = S of the subsets, E = entropy, bit, E_T = E of the total population, E_i = E of the subsets

	N	S	S_i/S_T	E	$E_T - E_i$	Average, °C
Total population	1820	3.71	-----	3.806	-----	0.00
			Peczely types			
mCc	52	2.64	0.779	3.157	0.649	-1.34
AB	97	2.41	0.711	3.272	0.885	-2.48
CMc	47	3.03	0.892	3.252	0.633	-1.33
mCw	175	3.49	1.029	3.753	0.053	+2.41
Ae	313	2.78	0.818	3.449	0.357	+1.30
CMw	159	3.57	1.053	3.806	0.000	+1.49
zC	67	2.79	0.822	3.319	0.487	+1.51
Aw	281	2.74	0.808	3.456	0.350	-0.94
As	102	2.50	0.737	3.268	0.538	+1.05
An	211	3.25	0.959	3.632	0.174	-0.73
AF	38	4.06	1.197	3.544	0.262	-2.36
A	263	3.27	0 965	3.691	0.115	-1.49
C	15	2.30	0.677	2.606	1.200	-0.65
Average of the values ($E_T - E_i$)					0.406	
Average weighted according to frequency Peczely types					0.282	
			ABG types			
1	166	3.38	0.010	3.721	0.085	+0.37
2	74	3.55	1.047	3.548	0.258	+1.25
3	78	3.99	1.177	3.992	-0.186	-0.97
4	118	3.30	0.973	3.634	0.172	-1.97
5	68	2.90	0.855	3.360	0.446	+1.78
6	86	4.17	1.230	3.912	-0.106	-0.88
7	184	3.64	1.074	3.817	-0.011	-0.05
8	228	2.59	0.764	3.348	0.458	-0.82
9	142	3.12	0.920	3.610	0.196	+0.42
10	113	3.37	0.994	3.593	0.213	+0.32
11	149	3.14	0.926	3.621	0.185	+0.46
12	58	3.83	1.130	3.731	0.075	+0.91
13	131	3.03	0.894	3.569	0.237	+0.58
14	107	2.65	0.782	3.398	0.408	+1.34
15	118	3.04	0.897	3.488	0.318	-1.10
Average of the values ($E_T - E_i$)					0.183	
Average weighted according to frequency ABG types					0.197	

Table IV

Standard deviations and entropies of the daily temperature anomalies of the winter season at Szeged (1961-1980) in the total population as well as in the subsets arranged according to the Peczely and the ABG macrosynoptic types.
N = number of cases, S = standard deviation, °C, S_T = S of the total population, S_i = S of the subsets, E = entropy, bit, E_T = E of the total population, E_i = E of the subsets

	N	S	S_i/S_T	E	$E_T - E_i$	Average, °C
Total population	1840	4.39	-----	4.139	-----	0.00
			Peczely types			
mCc	87	3.65	0.831	3.692	0.447	+0.60
AB	76	4.08	0.929	3.733	0.405	-2.56
CMc	66	3.79	0.863	3.689	0.450	-1.76
mCw	187	3.74	0.852	3.823	0.315	+2.87
Ae	301	3.85	0.877	3.909	0.230	+0.20
CMw	164	3.88	0.884	3.948	0.190	+1.71
zC	93	2.79	0.636	3.430	0.708	+3.57
Aw	233	3.42	0.779	3.685	0.453	+1.08
As	100	3.58	0.815	3.775	0.363	+2.00
An	265	3.72	0.847	3.857	0.281	-2.79
AF	47	3.50	0.797	3.450	0.689	-2.72
A	175	4.81	1.096	4.070	0.064	-3.23
C	16	2.58	0.587	2.483	0.440	+2.57
Average of the values ($E_T - E_i$)					0.481	
Average weighted according to frequency Peczely types					0.338	
			ABG types			
1	120	3.63	0.827	3.793	0.346	+1.88
2	133	4.06	0.925	3.888	0.251	+1.02
3	102	4.88	1.112	4.033	0.106	-2.47
4	114	3.94	0.897	3.801	0.338	+0.87
5	105	4.03	0.918	3.712	0.427	+2.04
6	107	4.82	1.098	4.073	0.066	+1.97
7	133	4.70	1.071	4.103	0.036	-1.78
8	115	2.97	0.677	3.557	0.582	+2.97
9	45	3.53	0.804	3.473	0.666	+1.88
10	83	4.75	1.082	4.109	0.030	-2.11
11	205	3.97	0.904	3.934	0.205	-1.60
12	83	3.30	0.752	3.625	0.514	+0.40
13	47	4.13	0.941	3.672	0.467	-3.28
14	32	3.25	0.740	3.355	0.784	+0.57
15	89	3.38	0.770	3.653	0.486	-2.59
16	75	3.67	0.836	3.587	0.552	-0.96
17	212	4.30	0.957	3.960	0.179	+1.52
Average of the values ($E_T - E_i$)					0.355	
Average weighted according to frequency ABG types					0.297	

Table V

Entropies of the directions of daily maximum wind gusts of the spring season at Szeged (1961-1980) in the total population as well as in the subsets arranged according to the Peczely and the ABG macrosynoptic types.
N = number of cases, E = entropy, bit, E_T = E of the total population, E_i = E of the subsets

	N	E	$E_T - E_i$
Total population	1840	3.788	-----
	Peczely types		
mCc	118	3.116	0.672
AB	119	3.437	0.351
CMc	95	3.380	0.408
mCw	244	3.675	0.113
Ae	208	3.331	0.457
CMw	188	3.647	0.141
zC	98	3.480	0.308
Aw	256	3.280	0.508
As	52	3.551	0.237
An	237	3.743	0.045
AF	86	3.466	0.322
A	101	3.814	-0.026
C	38	3.296	0.492
Average of the values ($E_T - E_i$)			0.310
Average weighted according to frequency Peczely types			0.291
	ABG types		
1	103	3.525	0.263
2	234	3.733	0.055
3	123	3.623	0.165
4	76	3.790	-0.002
5	106	3.728	0.060
6	67	3.654	0.134
7	177	3.760	0.028
8	56	3.430	0.358
9	8	3.000	0.788
10	164	3.727	0.061
11	68	3.463	0.325
12	34	3.245	0.543
13	76	3.659	0.129
14	136	3.655	0.133
15	97	3.615	0.173
16	70	3.510	0.278
17	55	3.394	0.394
18	79	3.582	0.206
19	111	3.489	0.299
Average of the values ($E_T - E_i$)			0.231
Average weighted according to frequency ABG types			0.159

Table VI

Entropies of the directions of daily maximum wind gusts of the summer season at Szeged (1961-1980) in the total population as well as in the subsets arranged according to the Peczely and the ABG macrosynoptic types.
N = number of cases, E = entropy, bit, E_T = E of the total population, E_i = E of the subsets

	N	E	$E_T - E_i$
Total population	1840	3.735	-----
	Peczely types		
mCc	154	3.172	0.563
AB	133	3.229	0.506
CMc	53	3.033	0.702
mCw	156	3.525	0.210
Ae	147	3.470	0.265
CMw	74	3.678	0.057
zC	89	3.517	0.218
Aw	419	3.212	0.523
As	29	3.388	0.347
An	261	3.657	0.078
AF	91	3.476	0.259
A	207	3.746	-0.011
C	27	3.176	0.559
Average of the values (E_T - E_i)			0.329
Average weighted according to frequency Peczely types			0.311
	ABG types		
1	260	3.724	0.011
2	136	3.536	0.199
3	373	3.632	0.103
4	210	3.752	-0.017
5	277	3.519	0.216
6	105	3.535	0.200
7	308	3.797	-0.062
8	171	3.665	0.070
Average of the values (E_T - E_i)			0.090
Average weighted according to frequency ABG types			0.075

Table VII

Entropies of the directions of daily maximum wind gusts of the autumn season at Szeged (1961-1980) in the total population as well as in the subsets arranged according to the Peczely and the ABG macrosynoptic types.
N = number of cases, E = entropy, bit, E_T = E of the total population, E_t = E of the subsets

	N	E	$E_T - E_t$
Total population	1820	3.756	-----
Peczely types			
mCc	52	3.157	0.599
AB	97	3.020	0.736
CMc	47	3.294	0.462
mCw	175	3.296	0.460
Ae	313	3.053	0.703
CMw	159	3.540	0.216
zC	67	3.269	0.487
Aw	281	3.180	0.576
As	102	3.437	0.319
An	211	3.475	0.281
AF	38	3.083	0.673
A	263	3.846	-0.090
C	15	3.057	0.699
Average of the values ($E_T - E_t$)			0.371
Average weighted according to frequency Peczely types			0.416
ABG types			
1	166	3.518	0.238
2	74	3.520	0.236
3	78	3.640	0.116
4	118	2.885	0.871
5	68	3.690	0.066
6	86	3.422	0.334
7	184	3.472	0.284
8	228	3.752	0.004
9	142	3.727	0.029
10	113	3.590	0.168
11	149	3.685	0.071
12	58	3.165	0.591
13	131	3.641	0.115
14	107	3.301	0.455
15	118	3.520	0.236
Average of the values ($E_T - E_t$)			0.254
Average weighted according to frequency ABG types			0.228

Table VIII

Entropies of the directions of daily maximum wind gusts of the winter season at Szeged (1961-1980) in the total population as well as in the subsets arranged according to the Peczely and the ABG macrosynoptic types.
N = number of cases, E = entropy, bit, E_T = E of the total population, E_i = E of the subsets

	N	E	$E_T - E_i$
Total population	1800	3.720	-----
	Peczely types		
mCc	87	3.090	0.630
AB	76	3.350	0.370
CMc	66	3.350	0.370
mCw	187	3.314	0.406
Ae	301	2.990	0.730
CMw	154	3.422	0.298
zC	93	3.462	0.258
Aw	233	3.322	0.398
As	100	3.358	0.362
An	265	3.380	0.340
AF	47	2.776	0.944
A	175	3.608	0.112
C	16	3.078	0.642
Average of the values ($E_T - E_i$)			0.451
Average weighted according to frequency Peczely types			0.426
	ABG types		
1	120	3.326	0.394
2	133	3.517	0.203
3	102	3.573	0.147
4	114	3.561	0.159
5	105	3.554	0.166
6	107	3.486	0.234
7	133	3.482	0.238
8	115	3.362	0.358
9	45	3.030	0.690
10	83	3.469	0.251
11	205	3.534	0.186
12	83	3.401	0.319
13	47	3.075	0.645
14	32	3.544	0.176
15	89	3.623	0.097
16	75	3.564	0.156
17	212	3.433	0.287
Average of the values ($E_T - E_i$)			0.277
Average weighted according to frequency ABG types			0.254

References

AMBROZY, P. - BARTHOLY, J. and *GULYAS, O., 1983*: Determination of seasonal macrosynoptic types for the Atlantic-European region by cluster analysis. - Meteorológiai Tanulmányok, Vol.39.

AMBROZY, P. - BARTHOLY, J. and *GULYAS, O., 1984*: A system of seasonal macrocirculation patterns for the Atlantic-European region. - Időjárás, *88*. 3. pp.121-133.

GIRS, A.A. and *KONDRATOVICH, K.V., 1978*: Metody dolgosrochnyh prognozov pogody. - Gidrometizdat, Leningrad.

HESS, P. and *BREZOWSKY, H., 1953*: Katalog der Grosswetterlagen Europas. - Ber. D. Wetterd., US-Zone, Nr.33.

KOPPANY, G. - RABAI, A. and *SZALMA, J., 1977*: Útmutató ... (Guide-book ...) - Meteorológiai Tanulmányok, Vol.22, p.22.

KOPPANY, G., 1986: Az időjárás hosszabbtartamú előrejelzése. (The long-term forecast of weather.) - Tankönyvkiado, Budapest.

KOPPANY, G. and *KISS, A., 1985*: A hőmérséklet és a szélirány változékonysága Szegeden a Péczely-féle makroszinoptikus helyzetekben. (The variability of temperature and wind direction at Szeged in Péczely's macrosynoptic situations.) - Időjárás, *89*. 5., pp.269-277.

KOPPANY, G. and *KISS, A., 1987*: A hőmérséklet és a szélirány változékonysága Szegeden a Péczely-féle makroszinoptikus helyzetekben az átmeneti évszakokban. (The variability of temperature and wind direction at Szeged in Péczely's macrosynoptic situations in the transitional seasons.) - Időjárás, *91*. 1., pp.23-33.

NAMIAS, J., 1947: Extended forecasting by mean circulation methods. - Washington, D.C.

PECZELY, G., 1956: Adalékok Magyarország makroszinoptikus helyzeteinek hőmérsékleti viszonyaihoz. (Contribution to the thermal conditions of Hungary's macrosinoptic situations.) - Időjárás, *60*. pp.71-81.

PECZELY, G., 1957a: Grosswetterlagen in Ungarn. - OMI Kisebb Kiadványai, 30. Budapest.

PECZELY, G., 1957b: Áramlási viszonyok Magyarországon különböző makroszinoptikus helyzetekben. (Air current conditions in Hungary in diverse macrosynoptic situations.) - Időjárás, *61*. pp.408-419.

PECZELY, G., 1983: Magyarország makroszinoptikus helyzeteinek katalógusa (1881-1983). (Catalogue of Hungary's macrosynoptic situations.) OMSZ Kisebb Kiadványai, 53.

SINDELY, P., 1985: The homogenious temperature series at Szeged for 110 years (1871-1980). - Acta Climatologica Szegediensis, Tom. XVIII-XX., Fasc. 1-4. pp.109-124. Szeged.

TAR, K., 1985: Magyarország szélklímájának komplex statisztikai elemzése. (Complex statistical analysis of Hungary's wind climate.) A candidate dissertation. Manuscript.

DETERMINATION OF SEASONAL MACROSYNOPTIC TYPES USING CLUSTER ANALYSIS AND ROTATED EOF ANALYSIS

by

Judith Bartholy

CENTRAL METEOROLOGICAL INSTITUTE, BUDAPEST, HUNGARY

Évszakos makroszinoptikus típusrendszerek meghatározása rotált empirikus ortogonális függvényana-analízis és clusteranalízis felhasználásával. A tanulmány rövid összefoglalását adja egy sokéves vizsgálatsorozatnak, melyben kísérlet történt évszakos makrocirkulációs osztályozások létrehozására az atlanti-európai szektorban, illetve az északi hemiszféra térségére. A különböző matematikai statisztikai módszer módszerekkel létrehozott típusrendszerek összehasonlító elemzésére is kitér a dolgozat.

A short summary is presented of a research carried out in the last few years. In this work an attempt was made to establish seasonal macrocirculational classifications for the Atlantic-European region and for the Northern Hemisphere. Comparative examinations of macrosynoptic systems produced by different mathematical statistical methods are discussed too.

1. Introduction

As early as in the 1950s and 1960s climatological and macrosynoptical classifications were made by several researchers for example DZERDZEJEVSKIJ (1946), VANGENGEJM (BOLOTINSKAJA - 1964), HESS and BREZOWSKY (1969), LAMB (1972) etc., with different aims and for different geographical regions. In each case different criteria were taken as bases of classification (the geographical position of cyclones and anticyclones, the direction of ridges, etc.). A common feature of these early classifications was that both creating the classes and arranging the phenomena were subjective processes and were carried out with the help of the human eye and synoptical practice.

With the widerspread use of high-capacity computers more objective methods have become possible. A new branch of mathematics, cluster analysis deals with the problems of classification algorithms. Some good summaries on this topic are given by ANDERBERG (1973), SPATH (1980). Several attempts have been made in the recent past at meteorological application of clustering procedures: SULOCHANA (1980) made a precipitation classification for the region of India, HARTHAN (1984) classified the tropical cloud configurations, and PANAGIOTIS (1984) gave a classification of weather situations in Greece. KRUIZINGA (1979) and MARYON (1985) made typisation on the basis of 500 mb height fields.

In the last years we have also applied several kinds of clustering technique in our researches, and created objective macrocirculation systems for large regions. The aim of this work was to eliminate the subjectively coded HESS-BREZOWSKY macrosynoptic system from the analogous forecasting model used by the *Central Forecasting Institute of the Meteorological Service of Hungary*. In our first work [AMBROZY-BARTHOLY-GULYAS (1983)] we made a system for the Atlantic-European region. With the increased validity period of the forecasts, however, it become necessary to make a hemispheric scale system. So, later on, in our experiments we made attempts at hemispherical clustering of the 500 and 700 mb height level by means of different classification algorithms. Probably due to the high number of dimensions, these classes were not separeted from each other sufficiently. Therefore, prior to the use of the classification algorithms a procedure for feature extraction and for data reduction was carried out on the entire data base: the rotated empirical orthogonal function analysis.

2. Attempts at clustering

Since the meteorological application of clustering is not yet much used, I'm going to give a brief summary of the principles of the procedures we used and their place among the methods of clustering. Cluster analysis, as a rule, has a dual aim: first, to explore the structure of the set of objects; second, to select the separate objects in such a way that the similar ones get into the same group, while the differing ones are placed in different classes.

The cluster analysis method can be divided into two main types: the hierarchical and the non-hierarchical methods. The methods included in the first group constitute a hierarchical system of clusters in such way that any two clusters are either disjoint or one of them implies the other. The hierarchical methods belong either to the agglomerative or the divisive type, depending on whether they reach the hierarchical system of clusters by unification or by division. Non-hierarchical methods can also be divided into two parts, namely, the overlapping and the disjoint classifications, depending on whether the grouping allows overlappings between the cluster or not.

Another important component of cluster analysis, the connection function, is also of two types: similarity function or non-uniformity function, depending on whether they take their maximum values in case of similarity or non-uniformity of the objects. In the past years in our researches hierarchical agglomerative and non-hierarchical disjoint methods are used, and in every case the classification was performed with the use of a connection function of the similarity type.

3. Atlantic-European region

In our first clustering attempt based on the daily 500 mb height fields, we constructed a seasonal system for the Atlantic-European region. Here the separate types represented the macrocirculational situations most characteristic of the season. For determining the classes the dynamical *"k-means"* method worked out by *McQUEEN (1967)* was used which belongs to the non-hierarchical disjoint methods. In the algorithm the computation was carried out with similarity connection functions according to *EUCLIDEAN* metrics. In the iteratively approximating version of method, the stability of the system during the separate iterations was measured by the number of objects regrouped in a new type (non-identical with that of the previous iteration). *Figure 1* illustrates the pressure maps of AT_{500}, $RT_{500/1000}$ and of surface level of the 9^{th} spring type. The first one was obtained as a result of clustering, and the latter two were computed on the basis of the archive of the full time-series. The seasonal cluster system contains 19 spring, 8 summer, 15 autumn and 17 winter types. To measure the effectiveness of the types we considered the external and internal distances of the systems which, by definition, represent the distances between the class centers and the internal radius of the various classes respectively. Internal radius: the average distance of all the fields included in the given type, from the cluster center.

With this classification we succeeded in reducing the internal distances by 42 per cent, and in increasing the external distances on average by 60-70 per cent in comparison with the *HESS-BREZOWSKY* macrosynoptic system. This means a better filling and spanning of the physically given 80 dimensional space (the Atlantic-European region is represented by 80 grid point values). The good results of this systematization were confirmed by the comparative verification results obtained after its insertion in to the long-range forecasting model.

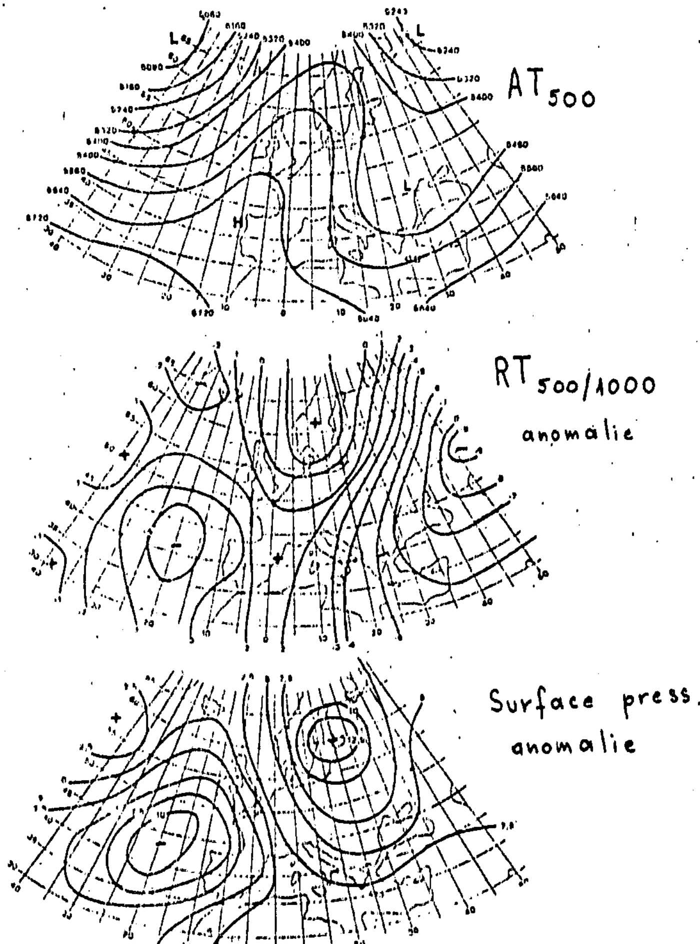


Fig. 1 9th class for spring season of the cluster system for the Atlantic-European region

4. The Northern Hemisphere

In our further experiments the investigated geographic region was expanded to the Northern Hemisphere; for technical reasons we switched over to the 700 mb level (on 500 mb there was a significant lack of data for this region in the data set at our disposal); and we chose a larger time scale: the fields of decade averages instead of daily fields. Like *FOLLAND (1985)* and *HAKICH (1985)* in their classifications for the Atlantic-European region, we also made our hemispherical cluster system for 6 natural seasons (Jan.-Febr., March-Apr., etc.) The low sample size does not cause a problem: as running means of decade fields were used in our researches, there was no reductions of the data set compared to the daily field set; only a smoothing was applied. The analysis was carried out on the data series of a 35 year period (1950-1984) of the *NMC (National Meteorological Center), Washington, D. C.*

Two attempts were made at clustering the running decade fields. In one case the hierarchical agglomerative, in the other case the non-hierarchical disjoint, non dynamical *"k-means"* method was used, similarly to the investigation of the Atlantic-European region. In both cases, for each season there were determined 10 types. In the investigations each hemispheric running means of 700 mb decade field was characterized by 358 grid point values, each representing approximately equal territories. The results satisfied us moderately: the types of the class systems did not separate well, presumably due to the high dimension numbers.

We were confident that carrying out an empirical orthogonal function analysis (EOF) prior to the implementation of the clustering procedures, the reduction in dimension number allowed by the concentration of the information will give better results. A comparative evaluation of the cluster systems will be discussed later.

5. Joint application of the rotated empirical orthogonal function analysis and the clustering

For reasons described above we applied a combined method, in which clustering was done after having carried out the EOF analysis of the fields and varimax rotation of the amplitudes. The EOF analysis was first used by *LORENZ (1956)* and *GILMAN (1957)*. In *CRADDOCK*'s investigations *(1969)* the hemispherical 500 mb fields are represented with the expansion coefficients of the fields expanded by eigenvectors of the correlation matrix, and the coefficients of the field are used as the data base of analog forecasting procedure. So the procedure is applied as a feature extraction and data reduction method. The EOF analysis - besides its several advantages described by *WALLACE (1972)*, *BARNSTON* and *LIVEZEY (1985)*, etc. - was used by us mainly in the *CRADDOCKIAN* sense. In the procedure the eigenvalue equation of the correlation matrix of the standardized data set is solved. The obtained eigenvectors are orthogonal, but their physical interpretation is difficult. Carrying out the varimax rotation analysed in detail among others by *HORAL (1981)* and *HARMAN (1960)*, we obtain results that can be interpreted better physically, at a price of a little deterioration of orthogonality. Inside the separate modes rotation maximalizes variance and eliminates smoothing caused by averaging, and it represents another feature extraction procedure.

After the EOF analysis and the rotation every field of every season is characterized by 10 coefficients and, after carrying out our iterative clustering procedure on these data as the data base, for each season there are obtained 10 types. In the clustering procedure there were made several attempts at selecting the initial cluster centers in order to accelerate the convergency of the method. Naturally, in order to obtain the final

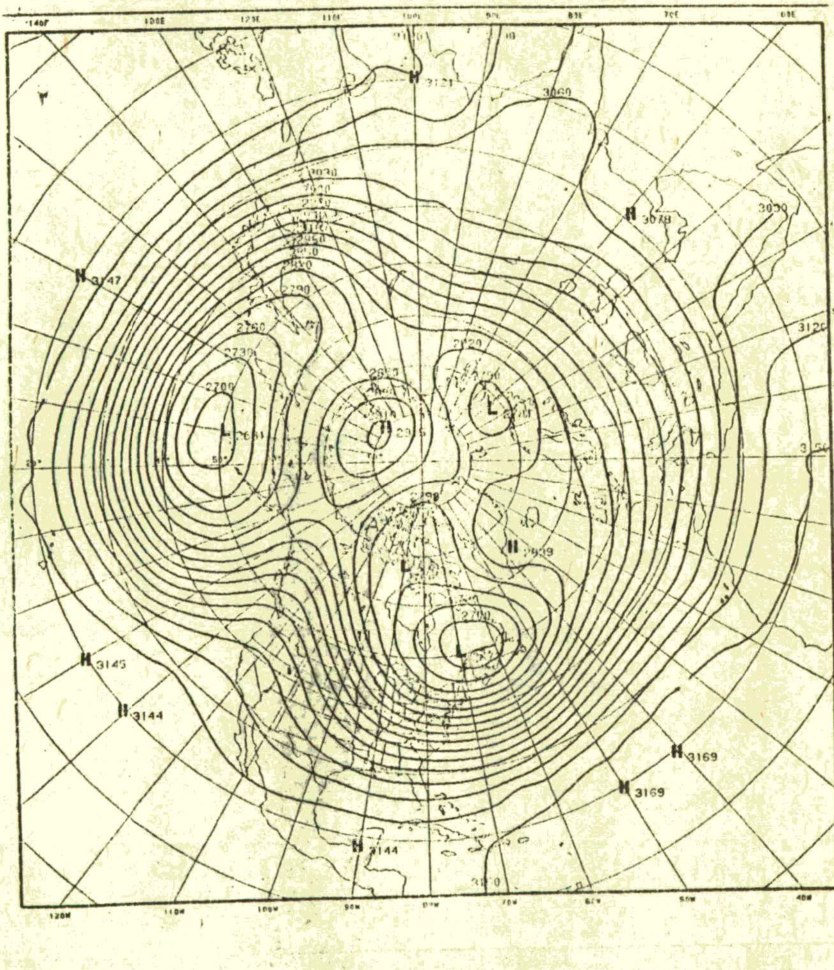


Fig. 2a 7th class for winter season of the northern hemispherical cluster system (the method use rotated EOF analysis and dynamical cluster technics), 700 mb

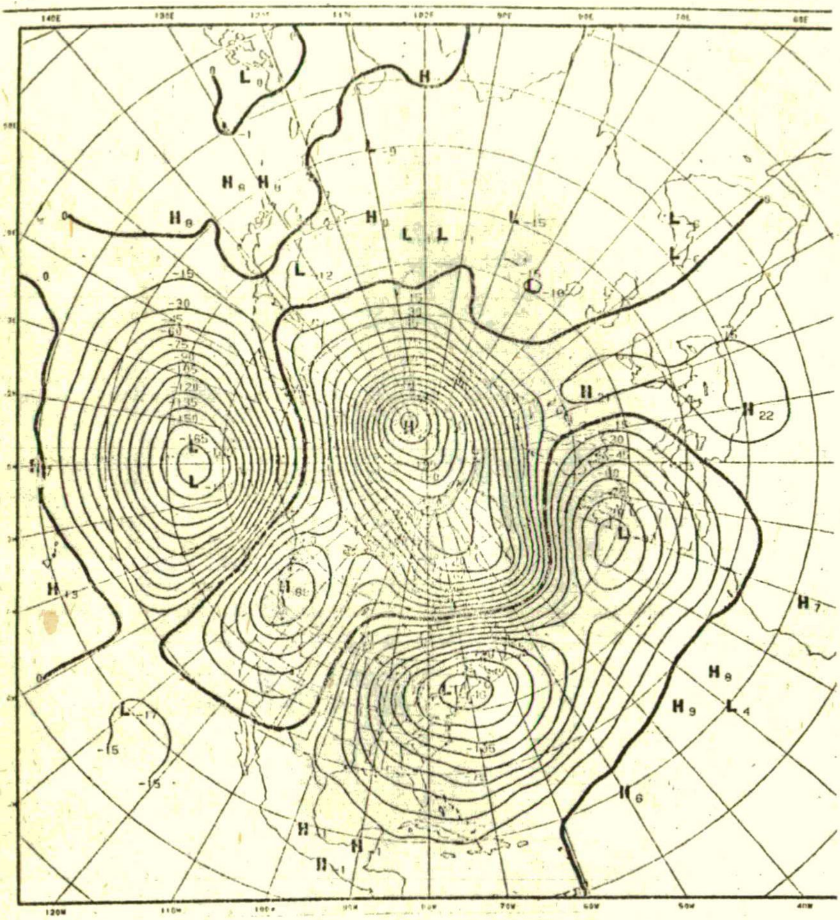


Fig. 2b 7th class for winter season of the northern hemispherical cluster system (the method used rotared EOF analysis and dynamical cluster technics), 700 mb, anomalies class centers, the inverse transformation of the rotation and the restoration of the 700 mb cluster centers have to be accomplished on the basis of the EOF coefficients and the eigenvectors. As an example, *Figure 2* illustrates the 700 mb height and anomaly fields of type *No.*7 of the winter season (January-February).

Comparative evaluation

During the 3 clustering experiments for the Northern Hemisphere and for the Atlantic-European region the stability of classifications was checked separately for each method. The mathematical background of the methods ensures the convergence of the algorithms in the classification procedures used. The invariance of the procedures on the randomly chosen initial cluster centers was checked.

In these methods each iteration sweeps through the whole data set once and every field is placed in a class. So, counting the fields placed in a new class (differing from the previous inclusion) a good index can be obtained for the stability of the cluster system. In *Table I* the final stability indices are demonstrated (for each method uniformly 12 iterations were made). It can be seen that, while in the case of the clustering after the hemispherical rotated EOF analysis, in the last iteration only 0.3 per cent of the fields were regrouped into a new class (altogether 7 fields), in the other two case their number was almost 5-10 times higher.

The external and internal distances of the three hemispherical cluster systems (using hierarchical, dynamical, EOF + dynamical methods) were compared. These results are shown in *Table II*. It can be seen that the procedure applying the EOF analysis compared to the hierarchical method; 1/ ensures a separation between the clusters about 30 per cent better (increase of the external distances); 2/ the different clusters are concentrated around the type centers 22 per cent better (reduction of the internal radius of the classes). These results are mean values, after averaging for 6 seasons.

The relatively little mean internal and great mean external distances can be evaluated positively if it is not accompanied by extreme frequency distribution for each type. But this condition is also fulfilled, because the amount of data included in the separate types is not less than 6 and not more than 17 per cent of the whole data set. The life-time of the separate types is on average two weeks, but naturally, it varies greatly varies depending on the seasons and types.

It was demonstrated that out of the 3 classification methods for the Northern Hemisphere, the system with clustering after a rotated EOF analysis is the best one in all aspects, therefore we are going to use this in our long-range forecasting analog method. Insertation into the model and the verification work is being done.

Table I

Instability indices for the two dynamical and the combined methods (the recorded field numbers by the last iteration given in percentage)

	Atl. - Eur. region	Northern Hemisphere	
	m e t h o d s		
	Dynamical	Dynamical	EOF + Dynamical
Instability indices	2.5 %	1.3 %	0.3 %

Table II

Separation indices between the classes and concentration indices inside the classes (changes of external and internal distances in percentage), calculated for each pars of the 3 methods

	m e t h o d s		
	Hierarch. - Dynamical	Dynamical - EOF + Dynamical	Hierarch. - EOF + Dynamical
Increasing of the external distances	11 %	18 %	29 %
Decreasing of the internal distances	8 %	14 %	22 %

References

AMBROZY, P.-BARTHOLY, J.-GULYAS, O., (1984): A system of seasonal macrocirculation pattern for the Atlantic- European region, Időjárás, Vol. 88. No.3., pp.121-133.

ANDERBERG, M.R., (1973): Clusteranalysis for applications, Academic Press, New York.

BARNSTON, A.G.-LIVEZEY, R.E., (1985): High resolution rotated EOF analysis of northern hemisphere 700 mb heights for predictive purposes, "9. Conf. on Prob. and Stat. in Atm. Sci." Virginia Beach, Am.Met.Soc., pp.290-298.

BARTHOLY, J.-KABA, M., (1985): Further development of seasonal climate forecasts for the territory of Hungary, Időjárás, Vol. 89. No.4., p.185.

CRADDOCK, J.M.-FLOOD, C.R., (1969): Eigenvectors for representing the 500 mb geopot. surface over the northern hemisphere, Quart.J.R. Met.Soc. No.405., p.576.

DZERDZEJEVSKIJ, B.L., (1946): Typification of circulation mechanism in northern hem. and characteristics of synoptic seasons, Moscow, Gidrometeoizdat.

FOLLAND, C.K.-COLMAN, A., (1985): A multivariate tech. for use in long-range forecasting, Proc.1.WMO Conf. Diag. Pred. Monthly-Seasonal Atm. Variations over Globe, Maryland.

GILMAN, D.L., (1957): EOF-s applied to thity-day forecasting, Sci.Rep. No.*1*. Contract AF19 (604)-1283, Dept. of Met. M.I.T. Cambridge, Mass.

HARMAN, H.H., (1960): Modern factor analysis, The University of Chicago Press, London.

HARTMAN, D.L., (1980): Some implication of the mesoscale circ. in trop. cloud clusters for large-scale dyn. and clim. - J. of the Atm. Sci., Vol.*41*. No.1., pp.113-121.

HESS, P.-BREZOWSKY, H., (1969): Katalog der Grosswetterlagen Europas, Ber. Wetterd. Offenbach, No.*113*.

HOREL, J.D., (1981): A rot. principal comp. anal. of the interannual variability of the Northern Hem. 500 mb height field, Mon.W.Rev. Vol.*109*., pp.2080-2092.

KRUIZINGA, S., (1979): Objective classification of daily 500 mb patterns, Bull. of six Conf. on Prob. and Stat. in Atmospheric Science of Amer. Met. Soc.

LAMB, H.H., (1972): British Isles weather types and a register of the daily sequence of circulation patterns, Geophys. Mem., London 16. No.*116*.

LORENZ, E.N., (1956): EOF-s statistical weather prediction, Sci. Rep. No.*1*. Stat. Forecasting Project, Dept. of Met. M.I.T. Cambridge, Mass.

MACQUEEN,J., (1967): Some methods for classification and analysis of multivariate observations, Proc. of Fifth Berkeley Symp. on Prob. and Stat.

MARYON, R.H.-STOREY, A.M., (1985): A multivariate statistical model, for forecasting anomalies on half-monthly mean surf. pressure, Jour. of Clim. Vol.*5*., pp.561-578.

PANAGIOTIS, M., (1984): Weather-type classification by factor anal., Jour. of Clim. Vol.4., p.437.

SPATH, H., (1980): Cluster analysis algorithms for data reduction and classification of objects, John Wiley and Sons, New York.

SULOCHANA, G., (1980): Cluster analysis of rainfall stations of the Indian peninsula, Quart.J.R.Met.Soc. *106*., pp.873-886.

WALLACE, J.M., (1972): Empirical orthogonal representation of time series in the frequency domain, Jour.Appl.Met. Vol.*11*. No.6., pp.887-900.

ISOCHRONES OF THE WETTEST MONTHS IN CONTINENTAL AREAS

by

G. Koppany

A legcsapadékosabb hónapok isochronjai kontinentális területeken. A dolgozat célja, hogy bemutassa az év legcsapadékosabb hónapjának fáziseltolódását a kontinentális területeken. Adatbázisként éghajlati csapadékadatok szolgáltak, mégpedig Európából 122, a Szovjetunióból 66, Észak-Amerikából 70, Dél-Azsiából 72, Magyarországról 750 és kiegészítő vizsgálat céljára Ausztráliából 48 állomásról. Meglehetősen szoros korreláció mutatkozik az év legcsapadékosabb hónapjának fázisa és a földrajzi szélesség között Európában, a Szovjetunióban és Észak-Amerikában. A legcsapadékosabb hónap isochronjai többé-kevésbé bonyolult képet mutatnak Dél-Azsiában és Ausztáliában, másrészt jóval nagyobb állomás sűrűség használatával mezoklimatikus hatások mutathatók ki Magyarországon.

The purpose of this paper is to demonstrate the displacement in phases of maximum precipitation in continental areas. Climatic data are used of Europe (122 stations), Soviet Union (66 stations), North America (70 stations), South Asia (72 stations), Hungary (750 stations) and for additional investigation 48 stations of Australia. Rather close correlations exist between the phases of the wettest months and latitude in continental areas of Europe, Soviet Union and North America. The isochrones of the wettest months exhibit more or less complicated distribution in South Asia, Australia, while using much greater density of stations the effect of mesoclimatic factors is demonstrated in Hungary.

Introduction

The mean annual variation of precipitation, in a geographical region, is determined by two basic factors: seasonal features of the general atmospheric circulation and annual variation of the temperature in the same region. The *former factor* produces e.g. dry summers in Mediterranean climate due to meridional shift of the subtropical high pressure belt, and rainy winters, when extratropical cyclones dominate in this area. The double maximum of annual variation in the equatorial zone is subject to the annual course of sun's declination, or the meridional shift of ITC. In this region the annual variation of temperature is negligible. Between 15-25° latitudes a single appearance of ITC results in one short rainy season.

The *second factor* is effective, if the annual amplitude of temperature is significant, i.e. in moderate and high latitudes and far from tempering influence of the sea. It is evident that in these areas the maximum of the rain occurs during the warmer half-year. Its simpliest explanation is that the air may contain much more water vapor in the warm season, hence the precipitable water is generally greater, than in the cold season. E.g. the specific humidity of satureted air is as much as 20 g/k at +25°C, 3,7 g/kg at 0°C, and 1,6 g/kg at -10°, respectively. The unstable sratification of the lower troposphere and the convective activity also contribute to formation of the summer rain.

The annual amplitude of temperature exceeds 20°C in most part of Europe, it varies between 25-60°C in the territory of Soviet Union, it reaches 20-40°C over a great part of North America. The purpose of this paper is to investigate the isochrones of the wettest months in these areas and to search regularities in their geographic distribution. This investigations includes only the territory of Europe, North America, Soviet Union, and South Asia; the formation of precipitation over the other part of Asia is strongly depending on the mountains resulting in complicated distribution of isochrones. The extratropical regions of South America, Africa, and Australia are too small for large scale analysis.

Amounts of annual precipitation, the wettest and driest months in Europe, Asia and America were tabulated by *ALISOV (1950)*. However, the numbers of stations in these tables are insufficient for a comprehensive analysis over these continents. Similar survey was given for various climatic regions by *KHROMOV (1968)*, but the avialable data in this worl are also insufficient. More detailed view is comprised in *World Survey of Climatology, Vol.7* about the wettest months in the Soviet Union in form maps and tables *(LYDOLPH, 1977)*. *BARRY* and *CHORLEY (1982)* give a survey of annual precipitation variation in North America. At the *Departement of Climatology in Szeged University (Hungary) G. KRISTOF (1987)* is engaged in analysing isochrones of the wettest months in co-operation with the author. Her research is limited for the continental territory of Europe.

It is noteworthy that the mean wettest month may change more or less from one decade to another due to long lasting variations in the general circulation. E.g. in Budapest, according to observations from 1841 *(RETHLY, 1947)* the wettest month in decadal average varies from May to November, though most frequently it appears in May or June. In this respect there are differences in data taken from many European stations, comparing the wettest months in different series (*Linkes Meteorologisches Taschenbuch, I.Band, 1962; Climatic Normals, WMO, No 117, T.P. 52, 1962; PECZELY, 1994*). Nevertheless, these differences do not influence significantly the geographical distribution of relevant isochrones in territories as large as continents.

Europe

The precipitation regime of Europe is determined by three climatic effects:

1. *Atlantic ocean* with its smooth annual distribution of precipitation, and relatively small annual variation.

2. *Mediterranean climate*, here the maximum rain occurs in colder half-year, and the annual variation is rather varying.

3. *Continental climate* with maximum precipitation in warmer half-year, and the annual variations are generally greater, than in the Atlantic climate.

In this research 113 European and 9 Turkish stations were used.* The wettest month of the year was established for each station, as well as the annual amount of precipitation, and the annual variations (ν) in per cent of the annual amount:

$$\nu = \frac{\text{max. monthly precip.(mm)} - \text{min. monthly precip.(mm)}}{\text{annual amount (mm)}} \cdot 100$$

The 123 stations were classified, as follows:

1. *Atlantic climate (A)*. Maximum monthly precipitation may occur in any season, the annual amount ranges generally between 700 and 1400 mm, the annual variations are as much as 4-8 per cent. 30 stations belong to this class.

2. *Mediterranean climate (M)*. Maximum monthly precipitation occurs in colder season, the annual amount is generally 400-900 mm, the annual variations range between 6 and 17 per cent. 24 European, and 4 Turkish stations belong to this region.

---

* See in APPENDIX, Table I

3. *Continental climate (C).* The wettest month occurs in warmer half-year, the annual amount is generally 400–1100 mm, the annual variations range between 6 and 12 per cent. 60 European and 5 Turkish stations belong to this area.

The maximum precipitation appears in colder half-year (October–March) *in 72.4 per cent of the stations* belonging to the *Atlantic climate, in 93 per cent of the stations* belonging to the *Mediterranean climate*, however it appears *in warmer half-year* (April–September) *in 97 per cent of the stations* belonging to the *continental climate.*

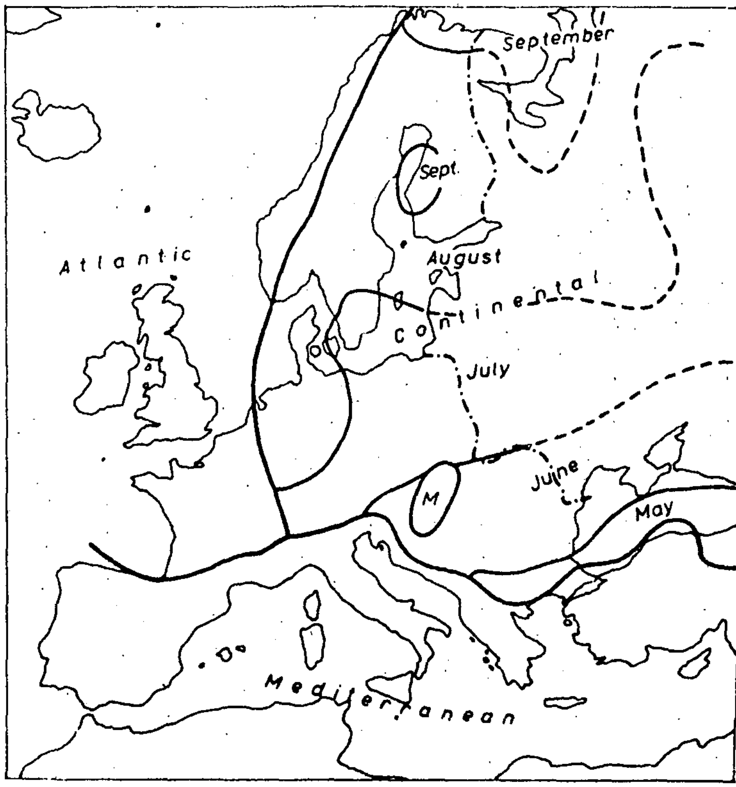


Fig.1

In *Fig 1* thick line denotes boundary between three climatic regions. In continental area thin lines denote the isochrones of the wettest months. The isochrones are denoted by dotted lines in European part of Soviet Union, because the Soviet stations will be discussed in the next chapter of this paper. In *Fig 1* it is evident that the maximum is lagging from one month to another towards the higher latitudes: over a part of Balkan Peninsula, Turkey and Hungary the wettest month is May, in northermost region it is September.

Marking the months of the year from Jynuary to December with numbers 1–12, a linear regression was defined expressing the relationship between the wettest months and the latitude. If Y denotes the wettest month (1–12) and X the latitude (in degrees), the linear regression can be written:

$$Y = 1.714 + 0.1004\,X. \qquad /1/$$

The correlation between X an Y: $r = = 0.648$.

It follows from equation /1/ that maximum rain is delaying by one month with increasing latitude by ten degrees.

KRISTOF (1987) using 140 European stations including the European part of Soviet Union obtained similar regression:

$$Y = 2.778 + 0.0803\ X,$$

and the correlation between X and Y : $r = 0.569$. According to this equation the maximum precipitation is delaying one month northwards in every 12.45 degrees (= 1/0.0803) latitude.

The interpretation of these results will be discussed later.

Soviet Union

In this analysis precipitation data of 66 stations both over the European and Asian territory of Soviet Union were used (*World Survey of Climatology, Vol.7, 1977*).* The *maximum precipitation occurs in 97 per cent of stations in warmer half-year* (April-September). This ratio correspondes to that obtained for continental area of Europe (see in previous chapter). The annual amounts range between 120 and 900 mm, the amplitude of annual variation is generally 6-20 per cent. Taken into account the total extension of this area (22 million square km), and the meridional extension from 35 to 75°N, the differences in annual amounts and in amplitudes of annual variations are not surprising.

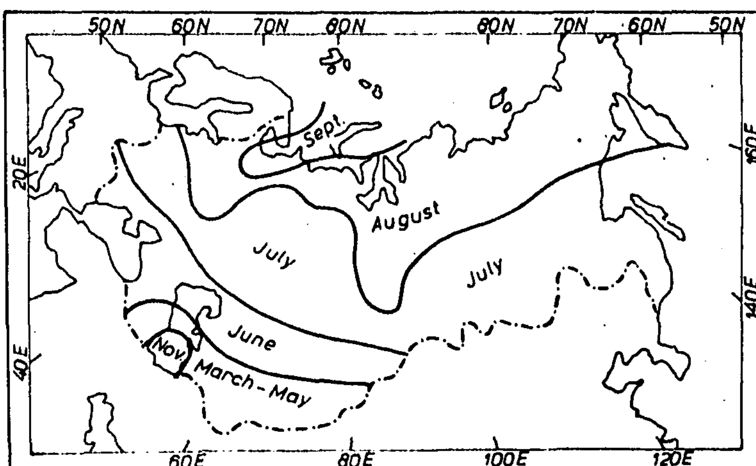


Fig. 2

Fig. 2 shows the isochrones of the wettest months over the territory of Soviet Union. South of 40°N there can be found a small area having Mediterranean character with maximum precipitation in March and November, respectively. North of this latitude the wettest month is delaying northwards: southernmost region it is May or June, in northernmost it is August or September. The relationship between wettest month and the latitudes can be expressed by a linear regression, as follows:

$$Y = 3.487 + 0.0668\ X \qquad /2/$$

---

* See in APPENDIX, Table II

According to equation /2/ the maximum rain is delaying by one month with increasing latitude in every 15 degrees (1/0.0668 ≈ 15). The correlation between *X* and *Y* : *r* = *0.422*. These results resemble those, which have been obtained for continental area of Europe, therefore their interpretation will be discussed later.

North America

From territory of North America (Alaska, Canada, U.S.A.) 70 stations were used (PÉCZELY, 1984).* As in case of Europe, three climatic regions were defined:

1. *Continental region* (43 stations). All stations of this area has a maximum precipitation in warmer half-year (April-September). The annual amount varies generally between 100 and 800 mm, the amplitude of annual variation ranges from 5 to 23 per cent. The differences can be understood taking into account that the locations ofthe stations vary from 33 to 74°N.
2. *Pacific region* (12 stations). The maximum precipitation occurs in 91.7 per cent of stations in the colder half-year (October-March). The annual amount ranges 300-1900 mm, the annual variations vary mostly from 6 to 10 per cent North of 41°N, and 16 to 22 per cent South of 41° latitude, respectively.
3. *Atlantic-Gulf region* (15 stations) is located along the coast of Atlantic ocean and Gulf of Mexico. The wettest month appears in 53 per cent of stations during the warmer half-year, in other words there is no characteristic annual course in precipitation.

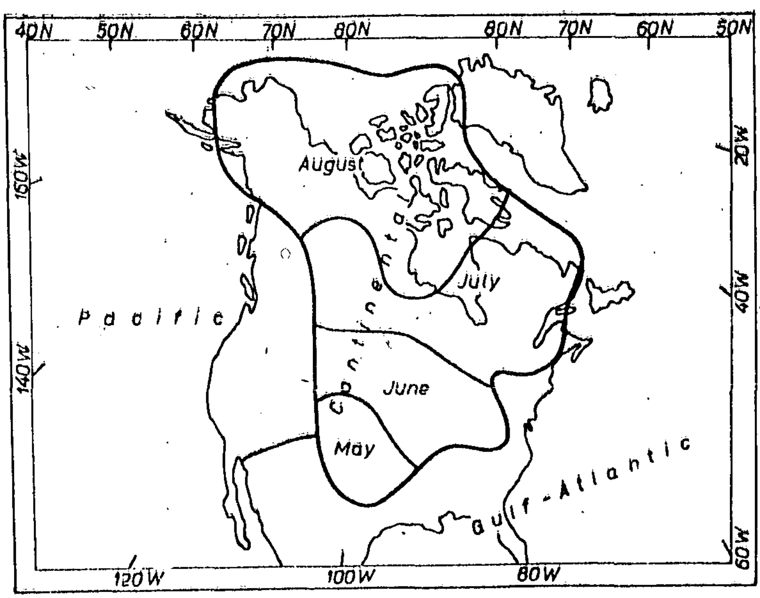


Fig. 3

Fig. 3 demonstrates the isochrones of maximum precipitation in continental region. In the southernmost zone, near 30°N latitude the wettest month is May, in Alaska and in great part of Canada, it is August.

---

* See in APPENDIX, Table III

The relationship between the annual phase of maximum rain and latitude is expressed by linear regression, as follows:

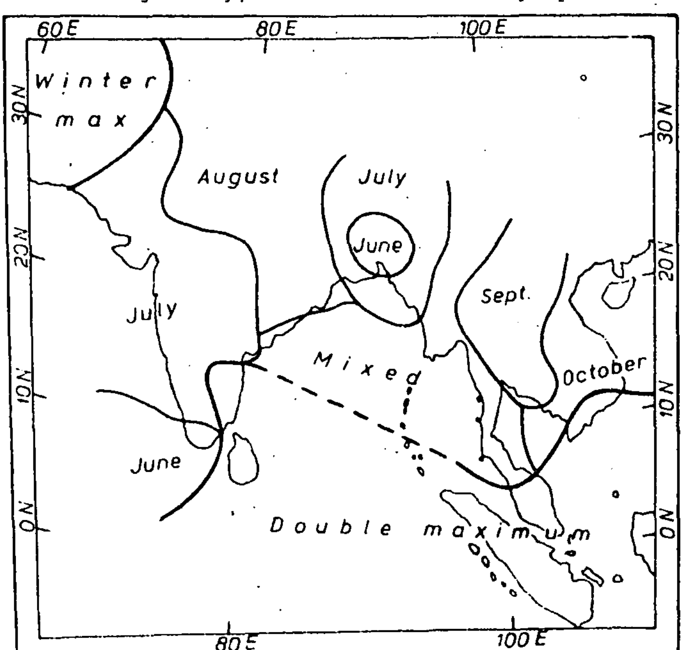
$$Y = 2.981 + 0.0749\ X. \qquad /3/$$

According to equation /3/ the maximum precipitation is delaying by one month northwards approximately in every 13 degrees (1/0.0749). The value of correlation (r) between X and Y is rather high: $r = 0.829$.

Additional investigations

The analysis of isochrones of maximum precipitation was performed for South Asian territory extending from Afghanistan to Vietnam, as well as for Australia. From South Asia 73*, from Australia 48 stations were used.

The precipitation regime of South Asia is rather complicated. In Afghanistan and in some stations of Pakistan the maximum precipitation occurs during the colder half-year, the annual variation ranges between 20 and 46 per cent, so it is rather significant. Approximately south of 10°N the annual variation is characterized by double wave with maximum in spring and autumn, respectively. Those correspond to the vernal and autumnal equinoxes. In some areas of monsoon rains the annual variation is characterized also by double maximum, but in rather irregular distribution. E.g. in North Pakistan the maximum rain occurs in March and August, in South Pakistan in January and July, in Bangladesh in June and August, in Burma in May and September. Nevertheless the isochrones of maximum monsoon rains shows significant regularity, the maximum is delaying northwards in great part of Pakistan and India, but east of 90°E it is delaying eastwards. While in southern India the maximum rain is observed in June, towards northeast it appears in July and August. Near Bay of Bengal maximum rain occurs in June or July, eastwards a phase displayment can be recognized, and the maximum rain shifts to September or October (*Fig. 4*).



It is suggested that the distribution of the wettest months in South Asia differs more or less from that in three areas discussed above. While west of Bay of Bengal the maximum rain delays towards

* See in APPENDIX, Table III and IV, respectively.

north, on the other hand east of Bay of Bengal the maximum delays eastwards and it appears in October over eastern part of Vietnam.

The precipitation regime of Australia can be devided essentially into two types: approximately between 10 and 30°S the wettest months are January, February or March. South of this zone the amximum precipitation occurs in June or July, i.e. in winter. The isochrones of summer maximum exhibit more or less regularity, but their interpretation is outside of our goal.

Finally, in order to explore mesoclimatic effects, it seems to be reasonable to examine the precipitation regime of Hungary using data of 750 stations (*HAJOSY, 1952*). Figures characterizing the density of stations in this area are: 124 square km/station and 11 km/station. Though all the wettest months appear in warmer half-year, from west to east one can recognize an interesting dichotony. From the eastern slopes of Alps to the Transdanubian Hills the maximum rain slides from July to August, while east of lake Balaton it alternates from May to June (*Fig. 5*).

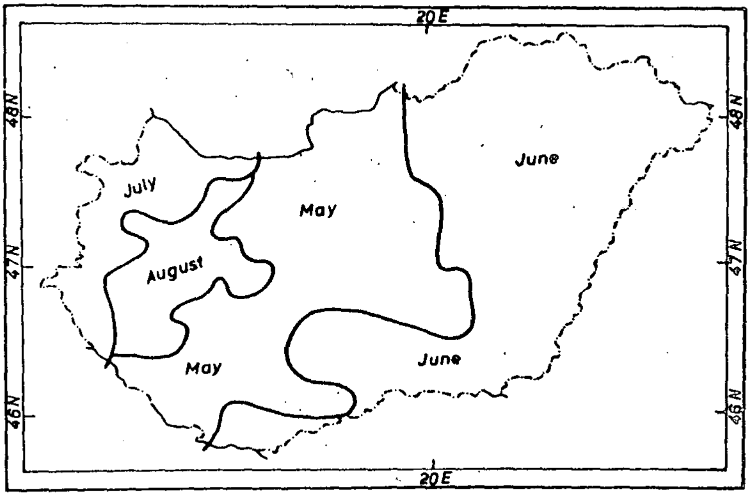


Fig. 5

This picture suggest that even by using a sufficiently high density of observations the isochrones of the wettest months provide regularity, and at the same time the mesoclimatic effects contribute in formation of precipitation regime.

Interpretations of results

The investigation of large scale precipitation regime in Europe, Soviet Union and North America proves convincingly that far enough from the oceans the wettest months are delaying northwards. The correlation coefficients between the phases of wettest months and latitudes are significant at 1 per cent level.

This property of the precipitation climate may be explained by the fact that the principal sources of atmospheric water vapor are provided by seas or oceans lying south of continents. Over a great part of Europe the primary source of moisture is Mediterranean- and Black-sea, respectively. For instance for observations in Hungary it has been pointed out that the largest amount of precipitation occurs at winds from *SW*, *WSW*, *SSW* and *SE*, while driest weather is expected at winds from *NE* and *ENE* (*KOPPANY, 1982*). In late spring or early summer abundant rain is falling in regions lying close to the *primary source of moisture*. After that the soaked soil serves as *secondary source of moisture*. It is probable that increasing transpiration of growing vegetation in late sping and in summer contributes to formation of secondary source of atmospheric moisture. The phenological phases of plants are delaying towards the higher latitudes during the warm season, and this fact, at least partly, may explain the delay of wettest months in higher latitudes over continental areas. Naturally other factors may be important too in formation of isochrones of the wettest months, e.g. the seasonal change of circulation, however the analysis pf possible factors is beyond our goal.

In Soviet Union numerous investigations have been made dealing with methodology of rain prediction. *PED'(1966)* assumed that the prediction of the next decade or month is derived from two sources: from external one, i.e. from advection of moisture, and from local source, i.e. from evaporation of soaked soil or evapotranspiration. According to several researches *(ZVEREV, 1960; YESAKOVA, 1963; FEDULOVA, 1964)* the advection of moisture depends on the intensity of meridional or zonal circulation. *ZVEREV (1960)* after having analysed the circulation at 850 hPa level concluded that abundant rain is expected when S wind is blowing. It is noteworthy that south of Soviet Union there are only two limited primary sources of moisture: Black-sea and Caspian-sea, at least in western partof the country, butin eastern part of its Asian territory the primary source of moisture is Pacific ocean. After all the effect of secondary source is evident over whole territory of Soviet Union.

In North America *W.H. KLEIN (1965)* made a profound research relating to the synoptic climatology of precipitation. He pointed out that different regions of the U.S.A. obtain the largest amount of moisture from different directions. The principal source of moisture is Pacific ocean on western coast, that of the largest central region is Gulf of Mexico, in eastern coast it is Atlantic ocean. The main portion of precipitation falling over North America originates probably from evaporation of ocean in low latitudes. Therefore it is very plausible assumption that at the beginning of warmer half-year the southernmost region obtain abundant rain, then the soaked soil serves as secondary source of moisture, and the maximum precipitation shifts gradually northwards as it has been described above.

APPENDIX

Table I

List of stations used in Fig 1

Europe

Stations	φ	λ	Max.	v (%)	Class.
1. Vardo	70°23'N	31°06'E	IX	6.7	C
2. Tromso	69°39'N	18°57'E	X	6.7	A
3. Bodo	67°17'N	14°25'E	X	7.5	A
4. Trondheim	63°25'N	10°27'E	X	5.8	A
5. Bergen	60°24'N	5°19'E	X	7.8	A
6. Oslo	59°56'N	10°44'E	VIII	9.4	C
7. Haparanda	68°50'N	24°09'E	VIII	12.4	C
8. Östersund	63°10'N	14°40'E	VIII	14.0	C
9. Härnösand	62°28'N	15°57'E	XI	7.9	A
10. Karlstad	59°22'N	13°28'E	VIII	8.9	C
11. Stockholm	59°21'N	18°04'E	VIII	9.0	C
12. Jönköping	57°46'N	14°11'E	VII	8.8	C
13. Göteborg	57°42'N	11°58'E	VIII	8.5	C
14. Sodenkylä	67°22'N	26°34'E	VII	10.6	C
15. Kajaani	64°17'N	27°41'E	VII	9.4	C
16. Vaasa	63°03'N	21°46'E	IX	9.1	C
17. Luonetjärvi	62°24'N	25°40'E	VIII	9.5	C
18. Turku	60°31'N	22°16'E	VIII	9.2	C
19. Helsinki	60°12'N	24°55'E	VIII	5.2	C
20. Thorshavn	62°03'N	6°45'W	XII	6.5	A
21. Kobenhavn	55°41'N	12°33'E	VII	6.5	C
22. Lerwick	60°08'N	1°11'W	XII	6.6	A
23. Stornoway	58°13'N	6°20'W	X	6.3	A
24. Aberdeen	57°12'N	2°12'W	XI	4.9	A
25. Aldergrove	54°39'N	6°13'W	VII;XII	5.4	A
26. Manchester	53°21'N	2°16'W	VIII	4.5	A
27. London	51°28'N	0°19'W	XI	4.4	A
28. Plymouth	50°21'N	4°07'W	XI-XII	6.0	A
29. Gorleston	52°35'N	1°43'W	XI	5.3	A
30. Belmullet	54°14'N	10°00'W	XII	6.7	A
31. Dublin	53°22'N	6°21'W	IX	3.7	A
32. Valencia	51°56'N	10°15'W	XII	6.2	A
33. De Bilt	52°06'N	5°11'E	VIII	5.6	A
34. Bruxelles	50°48'N	4°21'E	X	5.9	A
35. Le Havre	49°31'N	0°04'E	XI	5.8	A
36. Brest	48°27'N	4°25'W	XII	8.3	A
37. Paris	48°58'N	2°27'E	VIII	5.1	A
38. Nantes	47°10'N	1°37'W	XII	5.8	A
39. Bordeaux	44°50'N	0°42'E	XII	6.7	A
40. Lyon	45°43'N	4°57'E	IX	5.9	A
41. Toulouse	43°37'N	1°22'E	V	4.7	A
42. Nice	43°40'N	7°12'E	XI	12.6	M

Table I

Europe

Stations	φ	λ	Max.	v (%)	Class.
43. Bastia	42°33'N	9°29'E	X	13.6	M
44. Ajaccio	41°55'N	8°48'E	XII	13.1	M
45. La Coruna	43°22'N	8°22'W	XII	11.3	A
46. Zaragoza	41°39'N	0°53'W	X	5.3	M
47. Madrid	40°25'N	3°41'W	X	9.6	M
48. Barcelona	41°24'N	2°09'E	IX	8.2	M
49. Mallorca	39°36'N	2°42'E	X	15.4	M
50. Sevilla	37°24'N	6°00'W	III	15.9	A-M
51. Gibraltar	36°09'N	5°21'W	I	18.8	A
52. Lisboa	38°46'N	9°08'W	III	15.2	A
53. Lübeck	53°54'N	10°42'E	VII-VIII	6.6	C
54. Hamburg	53°38'N	10°00'E	VIII	6.4	C
55. Marburg	50°49'N	8°46'E	VIII	5.6	C
56. Karlsruhe	49°00'N	8°23'E	VIII	4.9	C
57. Augsburg	48°22'N	10°54'E	VII	8.8	C
58. Partenkirchen	47°30'N	11°06'E	VII	9.4	C
59. Greifswald	54°06'N	12°07'E	VII	6.5	C
60. Potsdam	52°23'N	13°04'E	VII	6.6	C
61. Dresden	51°07'N	13°41'E	VII	11.3	C
62. Zürich	47°23'N	8°34'E	VII	6.9	C
63. Genève	46°12'N	6°09'E	IX	5.6	A
64. Wien	48°15'N	16°22'E	VII	6.5	C
65. Salzburg	47°48'N	13°00'E	VII	9.5	C
66. Graz	46°59'N	15°27'E	VI	11.3	C
67. Mar. Lazne	49°58'N	12°42'E	VII	5.4	C
68. Praha	50°05'N	14°25'E	VII	11.6	C
69. Brno	49°12'N	16°34'E	VI	11.3	C
70. Oravsky Podzamok	49o15'N	19o20'E	VII	8.3	C
71. Presov	49°00'N	21°15'E	VII	10.1	C
72. Gdynia	54°31'N	18°33'E	VIII	8.5	C
73. Poznan	52°25'N	16°50'E	VII	8.3	C
74. Warszava	52°09'N	20°59'E	VII	11.2	C
75. Wroclaw	51°08'N	16°59'E	VII	8.9	C
76. Kielce	50°51'N	20°37'E	VII	9.8	C
77. Krakow	50°05'N	20°01'E	VII	9.5	C
78. Szombathely	47°15'N	16°36'E	VII	7.8	C
79. Pécs	46°05'N	18°15'E	V	4.4	C
80. Budapest	47°31'N	19°02'E	V	4.9	C
81. Szeged	46°15'N	20°09'E	VI	6.3	C
82. Nyiregyháza	47°58'N	21°43'E	VI	7.0	C
83. Baia Mare	47°40'N	23°35'E	VI	5.0	C
84. Timisoara	45°46'N	21°15'E	VI	6.5	C
85. Cluj	46°46'N	23°36'E	VI	11.9	C
86. Sibiu	45°48'N	24°09'E	VI	13.0	C

Table I

Europe

Stations	φ	λ	Max.	v (%)	Class.
87. Iasi	47°10'N	27°36'E	VI	9.3	C
88. Braila	45°17'N	27°59'E	VI	8.6	C
89. Bucuresti	44°25'N	26°06'E	VI	10.3	C
90. Constanta	44°11'N	28°40'E	VI	5.3	C
91. Pleven	43°46'N	24°35'E	VI	8.8	C
92. Varna	43°12'N	27°55'E	VI	7.4	C
93. Sofia	42°42'N	23°20'E	VI	8.6	C
94. Sandanski	41°34'N	23°17'E	XI	8.2	C
95. Udine	46°02'N	13°11'E	VI	6.4	M
96. Milano	45°28'N	9°11'E	X	6.0	M
97. Ancona	43°37'N	13°31'E	X	7.7	M
98. Roma	41°54'N	12°29'E	X	12.9	M
99. Napoli	40°51'N	14°15'E	XII	13.5	M
100. Palermo	38°07'N	13°21'E	XII	15.2	M
101. Cagliari	39°13'N	9°06'E	X	13.9	M
102. Thessaloniki	40°34'N	23°00'E	XI	9.4	M
103. Larisa	39°37'N	22°15'E	XI	10.2	M
104. Athens	37°58'N	23°43'E	XII	17.0	M
105. Ljubljana	46°04'N	14°34'E	X	7.8	M
106. Zagreb	45°49'N	15°58'E	VI	5.6	C
107. Beograd	44°48'N	20°27'E	VI	7.1	C
108. Sarajevo	43°52'N	18°26'E	VI	4.0	C
109. Nis	43°20'N	21°45'E	V	8.4	C
110. Titograd	42°26'N	19°16'E	XII	11.6	M
111. Skopje	42°00'N	21°06'E	XI	6.8	M
112. Dubrovnik	42°39'N	18°06'E	XII	14.4	M
113. Luga (Malta)	35°51'N	14°29'E	X	24.2	M
114. Tirana	41°18'N	19°48'E	X	10.8	M
115. Istambul	40°58'N	29°05'E	XII	11.5	M
116. Sinop	42°02'N	35°10'E	XI	9.6	M
117. Samsun	41°17'N	36°20'E	XI	7.4	M
118. Trabzon	41°00'N	39°43'E	XI	8.8	M
119. Ankara	39°57'N	32°53'E	V	11.5	C
120. Kars	40°36'N	43°05'E	V	12.4	C
121. Sivas	39°45'N	37°01'E	V	14.2	C
122. Kastamonu	41°22'N	33°47'E	V	12.2	C
123. Erzurum	39°55'N	41°16'E	V	12.1	C

Table II

List of stations used in Fig 2

Soviet Union

Stations	φ	λ	Max.	v (%)	Class.
1. Aldan	58°37'N	125°22'E	VII	13.25	C
2. Alma Ata	43°12'N	76°56'E	V	12.56	C
3. Anadyr	64°47'N	177°34'E	VIII	14.23	C
4. Apuka	60°26'N	169°40'E	VIII	10.21	C
5. Archangel	64°30'N	40°30'E	IX	7.05	C
6. Ashkhabad	37°58'N	58°20'E	III	20.48	M
7. Astrakhan	46°16'N	48°02'E	V	6.84	C
8. Baku	40°21'N	49°50'E	VIII	10.92	M
9. Balkhash	46°54'N	75°00'E	VI	13.04	C
10. Barnaul	53°20'N	83°48'E	VII	13.15	C
11. Batumi	41°45'N	41°40'E	IX	9.30	M
12. Blagoveshchensk	50°16'N	127°30'E	VII	19.66	C
13. Chita	52°01'N	113°20'E	VII	26.53	C
14. Chokurdakh	70°37'N	147°53'E	VIII	11.72	C
15. Dudinka	69°24'N	86°10'E	VIII	14.98	C
16. Yerbogachen	61°16'N	108°01'E	VII	16.10	C
17. Fergana	40°23'N	71°45'E	III	14.79	M
18. Shevchenko	44°33'N	50°17'E	VI	7.69	C
19. Gur'yev	47°01'N	51°51'E	VII	7.32	C
20. Ilirney	67°20'N	168°11'E	VII	20.39	C
21. Irkutsk	52°16'N	104°19'E	VII	20.52	C
22. Kaliningrad	54°42'N	20°37'E	VII	9.02	C
23. Karaganda	49°48'N	73°08'E	VII	11.72	C
24. Kaunas	54°53'N	25°53'E	VII	7.10	C
25. Kazan	55°47'N	49°11'E	VII	10.80	C
26. Kem	65°00'N	34°48'E	VIII	9.88	C
27. Kemerovo	55°23'N	86°04'E	VII	17.05	C
28. Kharkov	49°56'N	36°17'E	VII	8.28	C
29. Khatanga	71°50'N	102°28'E	VIII	12.16	C
30. Kiew	50°24'N	30°27'E	VII	5.69	C
31. Kirensk	57°46'N	108°07'E	VII	15.75	C
32. Kirov	58°39'N	49°37'E	VIII	8.92	C
33. Kishinev	47°01'N	28°52'E	VI	12.76	C
34. Klyuchu	56°19'N	160°50'E	XII	6.58	C
35. Kolpashevo	58°18'N	82°54'E	VIII	14.10	C
36. Krasnodar	45°02'N	39°09'E	VI	4.38	C
37. Krasnoyarsk	56°00'N	92°53'E	VII	17.66	C
38. Leningrad	59°58'N	30°18'E	VIII	9.30	C
39. Loukhy	66°05'N	32°59'E	VIII	10.27	C
40. Lvov	49°49'N	23°54'E	VII	10.08	C
41. Novaya Zemlya	72°23'N	52°44'E	IX	7.25	C
42. Minsk	53°52'N	27°32'E	VII	9.40	C
43. Minusinsk	53°42'N	91°42'E	VII	18.04	C
44. Moscow	55°45'N	37°34'E	VII-VIII	8.00	C
45. Murmansk	68°58'N	33°03'E	VIII	11.70	C
46. Mis Chelyuskin	77°43'N	104°17'E	VIII	4.76	C
47. Mis Smidta	68°55'N	179°28'E	VIII	8.44	C
48. Nar'yan Mar	67°39'N	53°01'E	VIII	11.90	C
49. Novgorod	58°21'N	31°15'E	VIII	10.67	C
50. Novorossiysk	44°42'N	37°48'E	XII	6.54	M

Table II

Soviet Union

Stations	φ	λ	Max.	v (%)	Class
51. Odessa	46°29'N	30°38'E	VI	6.43	C
52. Okhotsk	59°22'N	143°12'E	VII	15.61	C
53. Olenek	68°30'N	112°36'E	VIII	17.45	C
54. Omsk	54°56'N	73°24'E	VII	20.31	C
55. O. Dickson	73°30'N	80°14'E	VIII	13.91	C
56. Petrozavodsk	61°49'N	34°16'E	VII	10.73	C
57. Podk. Tunguska	61°36'N	90°00'E	VIII	10.62	C
58. Pyatigorsk	44°03'N	43°02'E	VI	13.28	C
59. Rostov-n.Donu	47°15'N	39°49'E	VI	5.38	C
60. Simferopol	45°01'N	33°59'E	VI	8.33	C
61. Surgut	61°15'N	73°30'E	VII	9.96	C
62. Sverdlovsk	56°44'N	61°04'E	VII-VIII	14.07	C
63. Syktyvkar	61°40'N	50°51'E	VII;IX	9.96	C
64. Tbilisi	41°41'N	44°57'E	V	10.92	C
65. Uzhgorod	48°38'N	22°16'E	VI	9.50	C
66. Volgograd	48°42'N	44°31'E	VI	6.92	C

Table III

List of stations used in Fig 3

North America

Stations	φ	λ	Max.	v (%)	Class.
1. Barrow	71°18'N	156°47'W	VIII	18.2	C
2. Barter (Is.)	70°08'N	143°38'W	VIII	14.4	C
3. Kotzebue	66°52'N	160°38'W	VIII	23.1	C
4. Fort Yukon	66°35'N	145°18'W	VIII	10.9	C
5. Fairbanks	64°49'N	147°57'W	VIII	17.4	C
6. Nome	64°30'N	165°20'W	VIII	17.4	C
7. Kodiak	57°30'N	152°45'W	XI	5.6	P
8. Anchorage	61°10'N	149°59'W	VIII	14.4	C
9. Juneau	58°22'N	134°35'W	X	10.0	P
10. Anette (Is.)	55°02'N	131°34'W	X	9.5	P
11. Alert	82°30'N	62°20'W	IX	16.2	C
12. Isachsen	78°47'N	103°32'W	VII	20.3	C
13. Resolute	74°43'N	94°59'W	VIII	23.6	C
14. Arctic Bay	73°00'N	85°18'W	VIII	13.8	C
15. Coppermine	67°49'N	115°05'W	VIII	14.6	C
16. Coral Harbour	64°12'N	83°22'W	VIII	11.7	C
17. Forth Smith	60°01'N	111°58'W	VII	10.9	C
18. Churchill	58°45'N	94°04'W	VIII	9.7	C
19. Trout Lake	53°50'N	89°52'W	VII	13.6	C
20. Winnipeg	49°54'N	97°15'W	VI	11.6	C
21. Vancouver	49°11'N	123°10'W	XII	10.3	P
22. North Bay	46°22'N	79°25'W	IX	5.4	A-G
23. Montreal	45°30'N	73°35'W	VII	2.5	C-A
24. Halifax	44°39'N	63°64'W	XI	3.5	A-G
25. Tatoosh (Is.)	48°23'N	124°44'W	XII	12.0	P

Table III

North America

Stations	φ	λ	Max.	v (%)	Class.
26. Portland	45°32'N	122°40'W	XII	16.5	P
27. Eureka	40°48'N	124°10'W	I-XII	16.7	P
28. San Francisco	37°47'N	122°45'W	I	21.9	P
29. Los Angeles	34°03'N	118°14'W	I	21.2	P
30. Salt Lake City	40°46'N	111°58'W	IV	9.0	P
31. Denver	39°46'N	104°53'W	V	15.0	C
32. Reno	39°30'N	119°47'W	I	14.4	P
33. Phoenix	33°26'N	112°01'W	VIII	14.1	A-G
34. El Paso	31°48'N	106°24'W	VII	12.9	A-G
35. Duluth	46°50'N	92°11'W	VI	11.4	C
36. Bismarck	46°46'N	100°45'W	VI	20.0	C
37. Kansas City	39°07'N	94°35'W	VI	9.7	C
38. Havre	48°34'N	109°40'W	VI	19.2	C
39. Amarillo	35°14'N	101°42'W	V	13.9	C
40. Buffalo	42°56'N	78°44'W	XI	2.9	A-G
41. Detroit	42°24'N	83°00'W	V	4.8	C
42. Chicago	41°47'N	87°47'W	VI	7.4	C
43. Indianopolis	39°44'N	86°17'W	VI	5.0	C
44. St. Louis	38°48'N	92°12'W	VI	7.7	C
45. Caribou	46°52'N	68°01'W	VII	5.6	C
46. Mt. Washington	44°16'N	71°18'W	IX	2.4	A-G
47. Parkersburg	39°16'N	81°34'W	VI	5.7	C
48. Nashville	36°07'N	86°41'W	I	7.0	A-G
49. Atlanta	33°39'N	84°25'W	III	6.2	A-G
50. Boston	42°13'N	71°07'W	XI	2.6	A-G
51. New York	40°47'N	75°58'W	VIII	3.8	A-G
52. Washington	38°31'N	77°03'W	VIII	5.9	A-G
53. Memphis	35°03'N	89°58'W	I	5.7	A-G
54. Little Rock	34°44'N	92°14'W	V	5.0	C
55. Dallas	32°51'N	96°51'W	V	8.4	C
56. New Orleans	29°57'N	90°04'W	VII	5.4	A-G
57. Houston	29°46'N	95°22'W	VII	6.1	A-G
58. Miami	25°48'N	80°16'W	X	10.9	A-G
59. Clyde	70°27'N	68°33'W	IX	18.4	C
60. Cambridge	69°07'N	105°01'W	VIII	14.8	C
61. Frobisher	63°45'N	68°33'W	VII	10.7	C
62. The Pas	53°58'N	101°06'W	VII	11.2	C
63. Edmonton	53°34'N	113°31'W	VII	13.7	C
64. Saskatoon	52°08'N	106°38'W	VII	12.8	C
65. Goose	53°12'N	70°54'W	VIII	4.2	C
66. Nitchequon	51°16'N	80°39'W	VII-VIII	10.2	C
67. F. Chimo	50°06'N	60°26'W	VIII	10.5	C
68. Dawson	64°04'N	139°26'W	VII	13.0	C
69. Boise	43°34'N	116°13'W	I	10.3	P
70. Lander	42°49'N	108°44'W	V	16.2	C

Table IV

List of stations used in Fig 4

South Asia

Stations	φ	λ	Max.	Class.
1. Salang	35°21'N	69°07'E	IV	W
2. Kabul	34°33'N	59°12'E	III	W
3. Herat	34°20'N	62°10'E	III	W
4. Kandahar	31°30'N	65°45'E	I	W
5. Ravalpindi	33°35'N	73°03'E	VIII	M
6. Quetta	30°11'N	67°00'E	II	W
7. Dalbandin	28°53'N	64°34'E	I	W
8. Peshawar	34°01'N	71°35'E	VIII	M
9. Lahore	31°33'N	74°20'E	VIII	M
10. Multan	30°12'N	71°26'E	VII	M
11. Jacobabad	28°18'N	68°28'E	VII	M
12. Hyderabad	25°23'N	68°25'E	VII	M
13. Pasni	25°16'N	63°29'E	VII	M
14. Karachi	24°48'N	66°59'E	VII	M
15. Gilgit	35°48'N	74°00'E	VIII	M
16. Leh	34°09'N	77°34'E	VIII	M
17. Simla	31°06'N	77°10'E	VIII	M
18. Darjeeling	27°03'N	88°10'E	VII	M
19. New Delhi	28°35'N	77°12'E	VII	M
20. Jaipur	26°55'N	75°52'E	VIII	M
21. Jodhpur	26°18'N	73°01'E	VIII	M
22. Bhuj	23°15'N	69°40'E	VII	M
23. Ahmadabad	23°04'N	72°38'E	VII	M
24. Veraval	20°54'N	70°22'E	VII	M
25. Patna	25°37'N	85°10'E	VIII	M
26. Allahabad	25°27'N	81°44'E	VIII	M
27. Calcutta	22°32'N	88°20'E	VII	M
28. Bombay	18°54'N	72°49'E	VII	M
29. Mangalore	12°54'N	74°51'E	VII	M
30. Kozhikode (Calicut)	11°15'N	75°47'E	VII	M
31. Indore	22°43'N	75°48'E	VII	M
32. Nagpur	21°06'N	79°03'E	VII	M
33. Jagdalpur	19°05'N	82°02'E	VIII	M
34. Hyderabad	17°27'N	78°28'E	VII	M
35. Belgaum	15°51'N	74°37'E	VII	M
36. Bangalore	12°58'N	77°35'E	IX	mixed
37. Cuttack	20°47'N	85°56'E	VIII	M
38. Vishakhapatnam	17°42'N	83°18'E	X	mixed
39. Madras	13°00'N	80°11'E	XI	mixed
40. Trivandrum	8°29'N	76°57'E	VI	M
41. Dibrugarh	27°29'N	95°01'E	VII	M
42. Gauhati	26°05'N	91°43'E	VI	M
43. Cherrapunji	25°15'N	91°44'E	VI	M
44. Port Blair	11°40'N	93°43'E	VI	M
45. Minicoy	8°18'N	73°00'E	VI	M
46. Trincomalee	8°35'N	81°15'E	V-XI	double
47. Colombo	6°54'N	79°52'E	V-X	double
48. Bogra	24°51'N	89°23'E	VIII	M
49. Dacca	23°46'N	90°23'E	VIII	M
50. Chittagong	22°21'N	91°50'E	VII	M

Table IV

South Asia

Stations	φ	λ	Max.	Class
51. Bhamo	24°16'N	97°12'E	VII-VIII	M
52. Mandalay	21°59'N	96°06'E	V-IX	M
53. Akyab	20°08'N	92°53'E	VII	M
54. Rangoon	16°46'N	96°10'E	VII	M
55. Tavoy	14°06'N	98°13'E	VI	M
56. Mergui	12°26'N	98°36'E	VII	M
57. Chiang Mai	18°47'N	98°59'E	IX	M
58. Phitsanulok	16°50'N	100°16'E	IX	M
59. Nakhon Rathchasima	14°58'N	102°07'E	IX	M
60. Bangkok	13°45'N	100°30'E	IX	M
61. Chumphon	10°27'N	99°15'E	XI	mixed
62. Songkhla	7°11'N	100°37'E	XI	mixed
63. Kuala Trengganu	5°20'N	103°08'E	III-XI	mixed
64. Pinang	5°18'N	100°16'E	V-X	mixed
65. Ipoh	4°34'N	101°06'E	IV-XI	mixed
66. Battambang	13°06'N	103°12'E	IX	M
67. Phnom Penh	11°33'N	104°51'E	X	M
68. Lao Kay	22°30'N	103°57'E	IX	M
69. Hanoi	21°02'N	105°50'E	VIII	M
70. Dong Hoi	17°29'N	106°56'E	X	M
71. Patl-Isles	16°33'N	111°37'E	X	M
72. Quang Ngai	15°08'N	108°50'E	XI	M
73. Ho-si-Minh	10°49'N	106°42'E	VI-X	double

Legend: W = Winter max.
M = Monsoon

References

ALISOV, B.P.,1950: Climatic regions of foreign countries. (In Russian). Moscow.

BARRY, R.G. and *CHORLEY, R.J.,1982:* Atmosphere, weather and climate. Methuen, London and New York.

CLIMATIC NORMALS, (CLINO) for the period 1931-1960 WMO, No. 117. T.P. 52. Genova, *1962*.

FEDULOVA, M.H.,1964: Method for quantitative prediction of 10-day precipitation in cold season. (In Russian). Meteor. i Gidrol. No. 10.

HAJOSY, F.,1952: Magyarország csapadékviszonyai. (Precitation conditions in Hungary.) OMI Hivatalos Kiadványai, 6. Budapest.

KHROMOV, S.P.,1968: Meteorology and climatology. (In Russian). Gidrometizdat, Leningrad.

KLEIN, W.H.,1965: Five-day precipitation patterns derived from circulation and moisture. - Humidity and Moisture. Vol. 2. New York.

KOPPANY G.,1982: Tiznapos csapadékelőrejelző módszer a magyarországi vízgyűjtő területekre. (Method of 10-day precipitation forecasting for catchment of Hungary.) Vízügyi Közlemények, Vol. 64. pp.220-234.

KRISTOF G.,1987: A legcsapadékosabb hónap izokron vonalainak függése a földrajzi szélességtől Európában. (Relationship between isochrones of the wettest months and latitudes in Europe.) - Thesis submitted for a degree. Szeged University.

LIDOPH, P.E. (ED.),1977: Climate of the Soviet Union. World Survey of Climatology, Vol. 7. London, New York.

LINKE's Meteorologisches Taschenbuch. (Neue Ausgabe) Leipzig, *1953*.

PECZELY G.,1984: A Föld éghajlata. (The Earth's Climate.) Tankönyvkiadó, Budapest.

PED', D.A.,1966: Method of 10-day precipitation forecasting. (In Russian). *Trudy CIP*, No. *147*.

RETHLY A.,1947: Budapest éghajlata. (Climate of Budapest.) Budapest.

YESAKOVA, N.P.,1963: Trudy Vsesoyuznogo nauchnogo meteor. soveschaniya. Tom. II. (Application od some circulation indices for 10-day forecasting of meteorological elements.)

ZVEREV, N.J.,1960: Statistical method for precipitation forecasting for 1-3 days in cold season. (In Russian). Trudy CIP, No. 97.

CYCLES AND QUASI-PERIODICITIES IN THE GLOBAL DISTRIBUTION OF SEA-LEVEL PRESSURE

by

L. MAKRA

Ciklusok és kváziperiodicitások a tengerszinti légnyomás földgömbi eloszlásában. A dolgozat azt elemzi, hogy a légnyomáseloszlás meridionális földgömbi profilját hány harmonikus összetevő hullám írja le megbízhatóan, továbbá, hogy kimutathatóak-e ciklusok, illetve kváziperiodicitások a tengerszinti légnyomás időbeli menetében a Földön. A reális periodicitásokat statisztikai szignifikancia-vizsgálat segítségével határoztuk meg. Az évi és félévi ciklusokat vektoriális formában közöltük.

Megállapítottuk, hogy a légnyomáseloszlás meridionális földgömbi profiljának 1. és 2. harmonikusa jól tükrözi a tengerszinti légnyomás egyenetlen eloszlását a két félteke között. A harmadik harmonikus - mely a globális légnyomási mező állandó vonásait mutatja - kisebb súlyú tényező. Az összes további harmonikus jelentéktelen a profil kialakításában. A tengerszinti légnyomás évi és félévi ciklusainak vizsgálata - eltérő adatbázison - lényegében ugyanazokra a következtetésekre vezetett, melyekre *HANN és SÜRING (1939)*, illetve *HSU és WALLACE (1976)* jutottak. A tengerszinti légnyomás idősorok harmonikus analízisével kapott periodikus összetevő hullámok statisztikai szignifikancia-vizsgálata alapján leszögezhetjük, hogy a tengerszinti légnyomás időbeli menetében a Földön csak kétféle ciklus létezik: a jellegzetes *12* havi és a kevésbé *markáns 6 havi. Számos szerző által mindezidáig megállapított nagy számú* és igen különböző, statisztikailag szignifikánsnak tekintett egyéb periódusok adatainkban nem tapasztalhatóak. A leggyakrabban kutatott periodicitások - a 11 éves napfoltciklus, a troposzférikus kvázikétéves (leginkább 26 hónapos) oszcilláció, s a Déli Oszcilláció - a tengerszinti légnyomás időbeli menetében nem tükröződnek.

The study analyses *how many harmonic component waves describe the meridional global profile* of sea-level pressure distribution reliably; in addition, it analyses whether cycles or quasi-periodicities can be found on the Earth, in the temporal course of sea-level pressure. The real periodicities are determined by a statistical significance test. The yearly and half-yearly cycles are presented in vectorial form.

It has been established that the 1^{st} and 2^{nd} harmonics of the meridional global profile of air pressure distribution well reflect the uneven distribution of sea-level pressure between the two hemispheres. The 3^{rd} harmonic, which shows the steady features of global air pressure field, is a factor of lesser importance. All the further harmonics are unimportant in the formation of this profile. The investigation of the yearly and half-yearly cycles of sea-level pressure has essentially led - on a different data basis - to the same conclusions to which *Hann and Süring (1939)*, as well as *Hsu and Wallace (1976)* had come. On the basis of the statistical significance test of the periodical component waves obtained by a harmonic analysis of the sea-level pressure time series it can be found that on the Earth, in the temporal course of sea-level pressure, there exist only two kinds of cycles: the characteristic *12*-month and the less sharp 6-month one. Consequently, the great number of, and very different, periodicities pointed out in the temporal course of sea-level pressure and *considered to be statistically significant by numerous* authors, are probably not real ones. The most frequently investigated periodicities - the 11-year sunspot cycle, the tropospheric quasi-biennial (mostly 26-month) oscillation, and the Southern Oscillation - are not reflected in the temporal course of sea-level pressure.

1. Object

The following questions arise: how many harmonic component waves do describe the meridional global profile of sea-level pressure distribution reliably, and what are the monthly and yearly courses of the individual component waves like? The first of the questions can be put with other words: how great a proportion of the full variance of the zonal monthly and yearly means of sea-level pressure can be explained by the first few harmonics? If this proportion is considerable, then producing further harmonics is unnecessary.

It will be examined, moreover, how the data base reflects the cycles and quasi-periodicities of sea-level pressure, which - in case of their reality - are of great importance from the point of view of long-range forecasts. The real periodicities will be determined by a statistical significance test. The yearly and half-yearly cycles will be presented in vectorial form.

2. Introduction

Besides the evident daily and yearly cycles, in sea-level pressure time series an astonishingly wide range of other periodicities have also been established. In the North Atlantic area, in surface and sea-level pressure time series periods of *2, 3.5-4.0, 5-6* and *11-12* months *(AMELUNG, 1962; LANDSBERG et al., 1966; BERKES, 1968; LOGINOV and SHUKHOMOZOVA, 1972)*, furthermore periods of *4-5* years *(LANDSBERG et al., 1966; SCHONWIESE, 1969, 1971)*, as well as of *5-6* years *(WAGNER, 1971; MICHELCHEN, 1981)* and of *21* years *(WAGNER, 1971)* have been discovered. In the Southern Hemisphere, in the time series of the air pressure differences between *January* and *July*, cycles of *3, 5, 11* and *18*-years can be found *(KHAMINOV, 1966)*. By the harmonic analysis of the Southern Oscillation Index *TRENBERTH (1976)* obtained a period of *3-6* years. The semi-annual mean zonal index of given temperate-belt latitudes (35-55°), derived from monthly mean *500-hPa* charts, shows *5,5-* and *10*-year periods *(WANG, 1963)*. In the intensity of the meridional circulation over the tropical Pacific Ocean *FU (1979)* found a fluctuation of *32-48*-month periods, *PECZELY (1978)* determined the same period in the time series of pressure anomalies over the subtropical zone of the South Pacific, and over the equatorial zone of the Pacific Ocean. *ANGELL and KORSHOVER (1968)* suppose that between latitudes *30°N* and *30°S* the periodicities of the two hemispheres are fundamentally in phase; in addition, they establish that in winter and spring there is a period of about 16 years at the *500-hPa* geopotential level over the Northern Hemisphere in the changes of meridional current, heat flux, zonal wind and temperature. By the harmonic analysis of the aridity index series over certain areas of India, *BHALME and JADHAV (1983)* discovered statistically significant quasi-periodicities of *3.3-6.6, 10* and *20* years. Of these periods, the first two are close to the modal peaks of the Southern Oscillation, suggesting that the oscillation of the aridity indexes can be brought into connection with the large-scale changes in air pressure over the Indo-Pacific. The other two periods (the *10-* and the *20*-year ones) are close to the 11-year sunspot cycle and the 22-year double sunspot cycle.

3. Data

The data basis of the study consists of the monthly mean sea-level pressure values of *247 stations* referring to the *30* years between *1951* and *1980 (Fig. 1)*.

From *17* stations - since they have incomplete data - we have uniformly taken into consideration the monthly mean values of the *23* years between 1958 and 1980 into. Among the stations there are weather ships *(39., 65., 66., 85., 91. and 108.)*, buoys *(166. and 184)*, and there are interpolated data *(84., 150., 198., 203., 208., 215., 236., 237., 245. and 247.)* as well. We have collected the pressure data series on the basis of the data of the volumes *"World Weather Record"*, as well as the mean sea-level pressure charts of monthly publications *"Monthly Climatic Data for the World"* and *"Die Witterung in Übersee"*.

The global distribution of the stations is relatively equal, but it is to be mentioned that, e.g., there are no data from China at all, and the number of stations is small in Siberia, as well as over the Pacific Ocean,

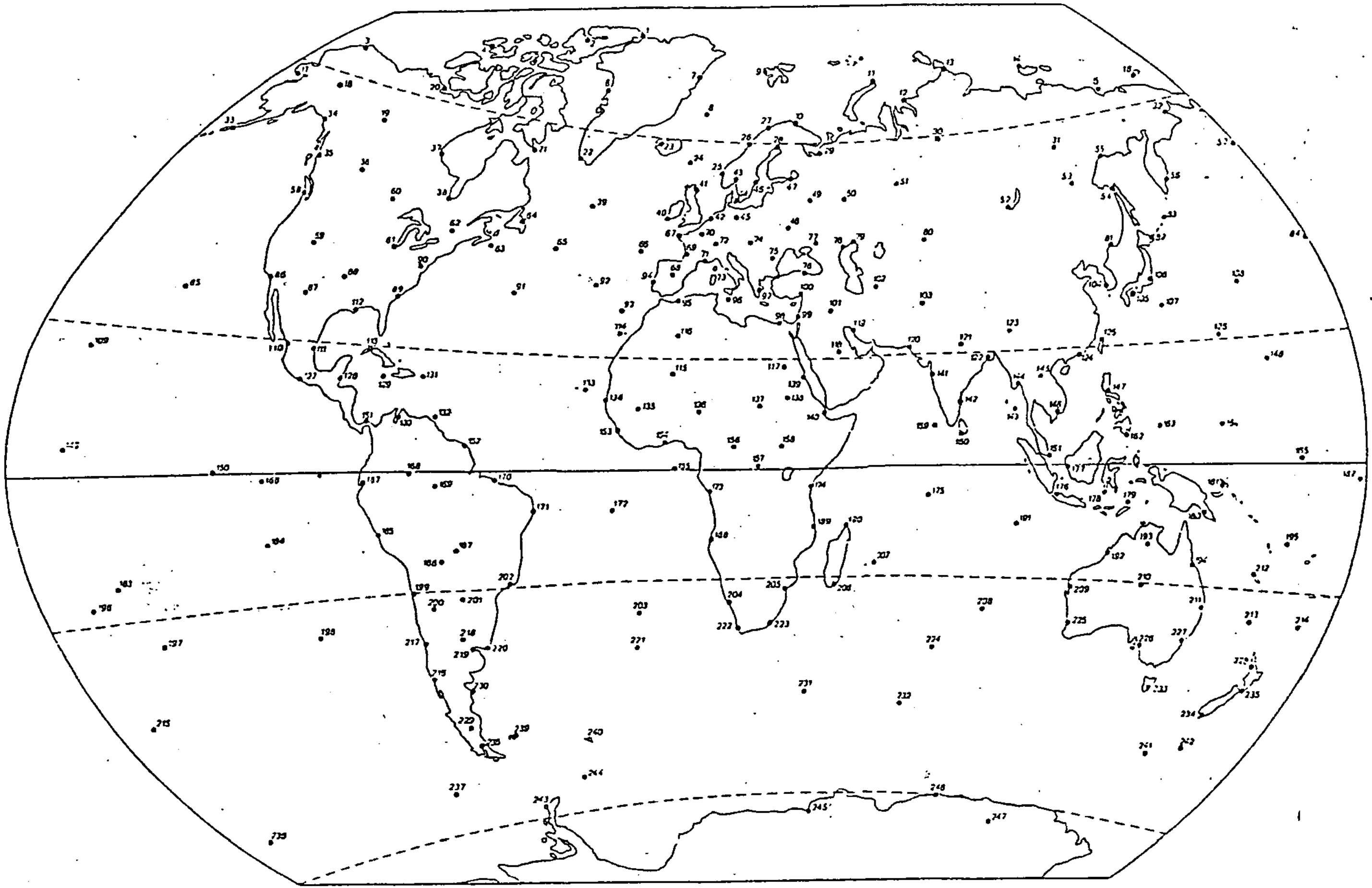


Fig. 1 Stations

furthermore, in the temperate-belt and polar regions of the Southern Hemisphere, too. The zonal distribution of the stations is included in *Table 1*.

Table 1

Zonal numbers of stations

90–80° N	2	0–10° S	17
80–70° N	14	10–20° S	13
70–60° N	17	20–30° S	19
60–50° N	24	30–40° S	14
50–40° N	27	40–50° S	7
40–30° N	24	50–60° S	7
30–20° N	18	60–70° S	5
20–10° N	22		
10– 0° N	17		
Northern Hemisphere	165	Southern Hemisphere	82

Earth 247

The distribution of the stations according to height above sea level is also determined *(Table 2)*.

Table 2

Percentage of stations found lower than a given height above sea level (m)

50 m	<	66.40 %
100	<	79.76
200	<	88.26
300	<	89.88
400	<	93.52
500	<	96.35
1000	<	99.18
1300	<	100.00

Results

The first five harmonic components of the samples, and their sums, consisting of the monthly and yearly means of sea-level pressure, by *10°* latitudes have been determined. Of them, those of the central months of each season, and those of the year are presented *(Figs. 2a, b, c, d, e)*. Investigations with similar purposes have already been performed by KAUFELD *(1972)* as well. The monthly mean sea-level pressure values, by *10°* latitudes, forming the basis of his investigations, had come from the data of the *International Geophysical Year (IGY)* – i.e. from the sea-level pressure values of globally *1,462* grid points measured at *1200 GMT* daily between *July 1, 1957 and December 31, 1958*. In this way KAUFELD *(1972)* produces and analyses the first 4 harmonics of the meridional profile of global sea-level pressure by *10°* latitudes.

According our computations it is sufficient to produce the first five harmonics of each sample, (the *5th* one will not be graphically published now) for these five components explain *87–90* per cent of the total variance

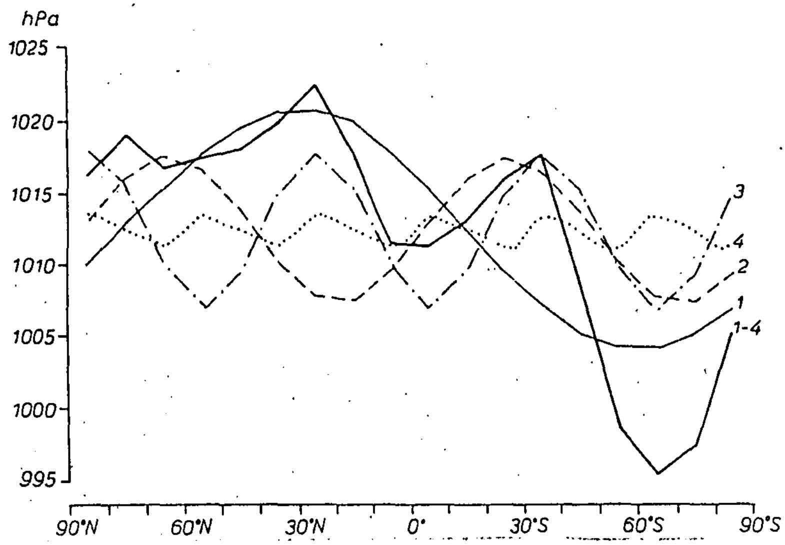


Fig. 2a The first four harmonics (1, 2, 3, 4) and their sum (1-4) of mean sea-level pressure, counted from the averages of mean monthly values at each 10th degree of latitude, January

of the original samples *(Table 3)*. The statistical significance of the amplitudes for the harmonics of the individual samples is indicated by the ratio A/E, where A is the amplitude and E is the mean value of the amplitudes. (A_{18}/E measures the statistical reality of the amplitudes of the first harmonic components for each *18*-element sample; A_9/E shows the statistical reality of the amplitudes of the second harmonic components for the same samples mentioned above, etc..) The 4th and 5th harmonics, e.g. contribute to the total variance of the individual samples *(Table 3)* in approximately the same and already an extraordinarily slight degree; consequently, they have little role in the modification of the meridional profiles of the monthly and yearly global mean sea-level pressure – as it is reflected by the graphic picture of the 4th harmonic as well *(Figs. 2a, b, c, d, e)*.

Table 3

Cumulative variance and statistical significance of harmonic components

	explained variance	A_{18}/E	A_9/E	A_6/E	A_5/E	A_4/E
January	0.904	*2.389*	1.448	1.533	0.338	0.301
April	0.878	1.819	*2.086*	1.477	0.292	0.359
July	0.878	1.880	*2.302*	1.051	0.106	0.330
October	0.874	*2.161*	1.854	1.308	0.172	0.410
Year	0.886	*2.068*	*1.971*	1.348	0.261	0.319

The italicized values are significant at the 95 per cent level

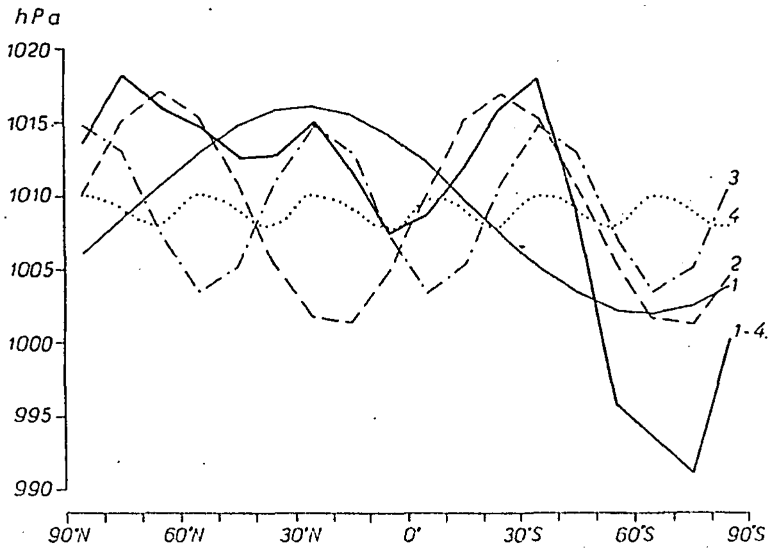


Fig. 2b The first four harmonics (1, 2, 3, 4) and their sum (1-4) of mean sea-level pressure, counted from averages of mean monthly values at each 10th degree of latitude, April

The sum of the first four harmonics clearly shows the most marked characteristic of the global distribution of sea-level pressure, i.e. the extraordinarily powerful decrease of air pressure in the southern hemispheric westerlies, in the subantarctic pressure trough. The subtropical high-pressure belt in the Southern Hemisphere is similarly characteristic, especially in the summer and autumn of the Northern Hemisphere. Its northern hemispheric counterpart is more characteristic only in winter, but in summer it disappears, and is, also in yearly average, less developed than the southern hemispheric one. The equatorial depression is the weakest in the summer of the Northern Hemisphere; in the other seasons of the year, as well as in the yearly average it definitely deepens. In spring and summer, in the polar region of the Northern Hemisphere, high pressure is more characteristic than in the subtropical belt. Air pressures are about equivalent over the two regions even in the yearly average, and the subtropical area has a higher pressures only in autumn and winter. In the temperate belt of the Northern Hemisphere, sea-level pressure has a local minimum, which exists during the whole year, but is the most characteristic in spring. The reason for this is that under the influence of increasing radiation the contrast of temperature between oceanic and continental surfaces, as well as between the regions of the lower and the higher latitudes increases greatly. That increases the pressure-gradient, so the intensity of the westerlies grows in this area; which brings about a more powerful decrease of pressure in the temperate belt.

The first harmonic shows the fact that air pressure is higher in the Northern Hemisphere than in the Southern Hemisphere. In summer the maximum is between the latitudes *10°N* and *20°N*, in the other seasons and in the yearly average it is between the latitudes *20°N* and *30°N*. On the other hand, according to KAUFELD's calculations *(1972)* the maximum in the annual mean can be found near the latitude *11°N*, i.e. in the vicinity of the thermal equator. In the KAUFELD's study *(1972)* the first harmonic indicates the fact that in lower latitudes air pressure is higher than over higher latitudes.

The second harmonic mostly shows the disproportions between the Northern and the Southern Hemisphere. Its maximums are not symmetrical to

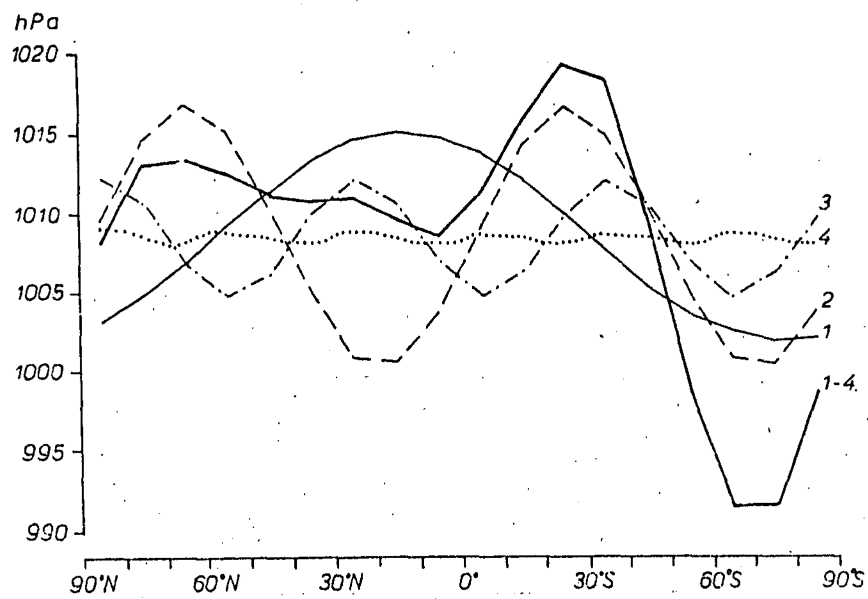


Fig. 2c The first four harmonics (1, 2, 3, 4) and their sum (1-4) of mean sea-level pressure, counted from averages of mean monthly values at each 10th degree of latitude, July

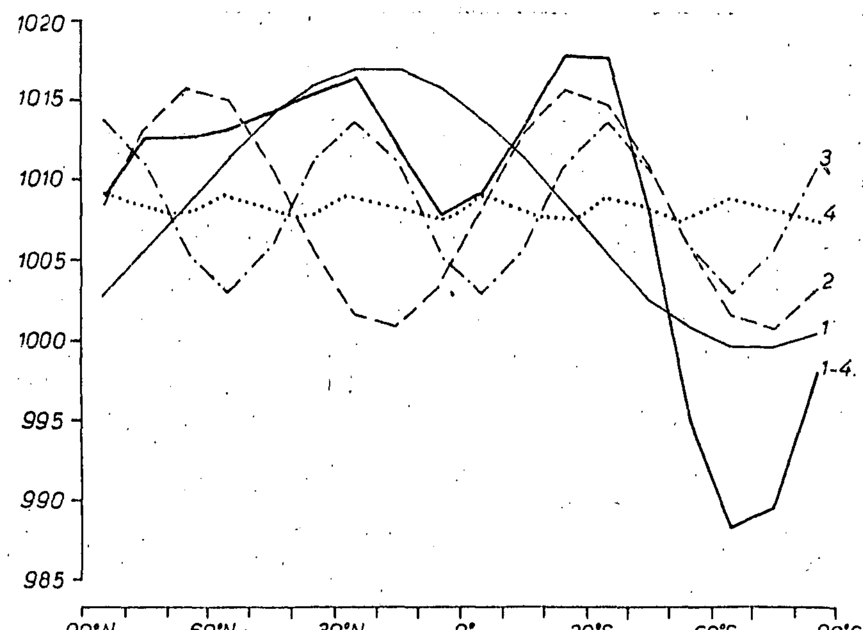


Fig. 2d The first four harmonics (1, 2, 3, 4) and their sum (1-4) of mean sea-level pressure, counted from averages of mean monthly values at each 10th degree of latitude, October

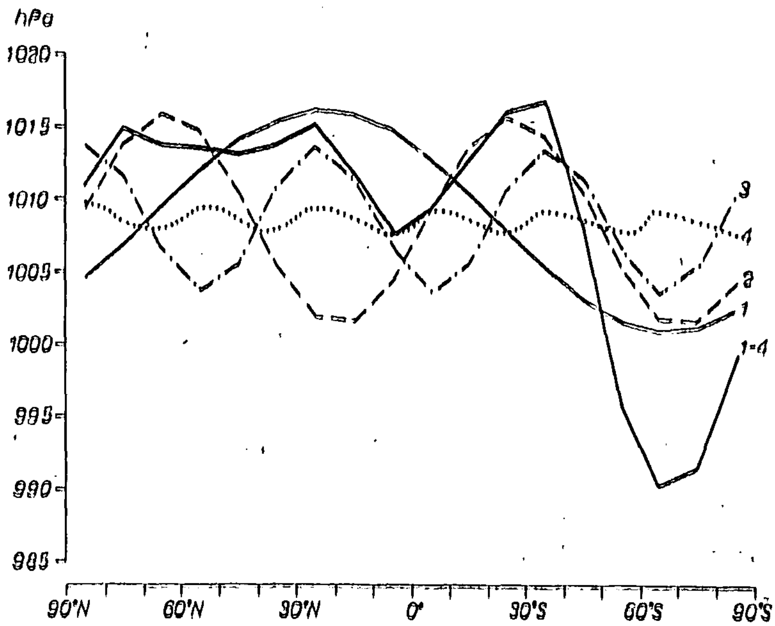


Fig. 2e The first four harmonics (1, 2, 3, 4) and their sum (1-4) of mean sea-level pressure, counted from averages of mean monthly values at each 10th degree of latitude, year

the equator, but seasonally and in the yearly average alike they shift northwards approximately by 20 degrees. In the yearly average, *KAUFELD (1972)* came to the same conclusion. In spring and summer the amplitude of the second harmonic is bigger than that of the first harmonic; in autumn and winter it is smaller; and it is smaller in the yearly average, too, where *KAUFELD (1972)* got a contrary result. The amplitude and the phase of the third harmonic are the most stable both seasonally and in the yearly average. It is almost symmetric to the equator, and shows the permanent global air pressure distribution: an equatorial low-pressure trough, subtropical high-pressure zones in the area of the latitudes *30°*, subpolar low-pressure belts in the neighbourhood of the latitudes *60°*, and polar high-pressure areas. As regards the yearly average, *KAUFELD (1972)* came to the same conclusion.

The role of the *4th* (and of each further) harmonic (and that of the 4th component according to *KAUFELD*'s calculations *(1972)* as well) in the forming of the meridional profiles of the monthly and yearly sea-level pressure is -in accordance with the earlier results - not significant *(Figs. 2a, b, c, d, e; Table 3)*.

Summarizing the facts mentioned above, the first and second harmonic components well reflect the uneven distribution of sea-level pressure between the two hemispheres. The third harmonic component, which shows the permanent features of global pressure field, is a factor carrying less weight.

Von HANN and SURING (1939) summarized the main results of the earlier works dealing with the annual course of surface pressure, as follows. Over the equatorial areas, the annual change is very slight. In the higher latitudes, the annual change can be put into three main types: 1. *continental type*, which is characterized by a pressure maximum in winter and a pressure minimum in summer; 2. with the *oceanic type*, the maximum is in summer, the

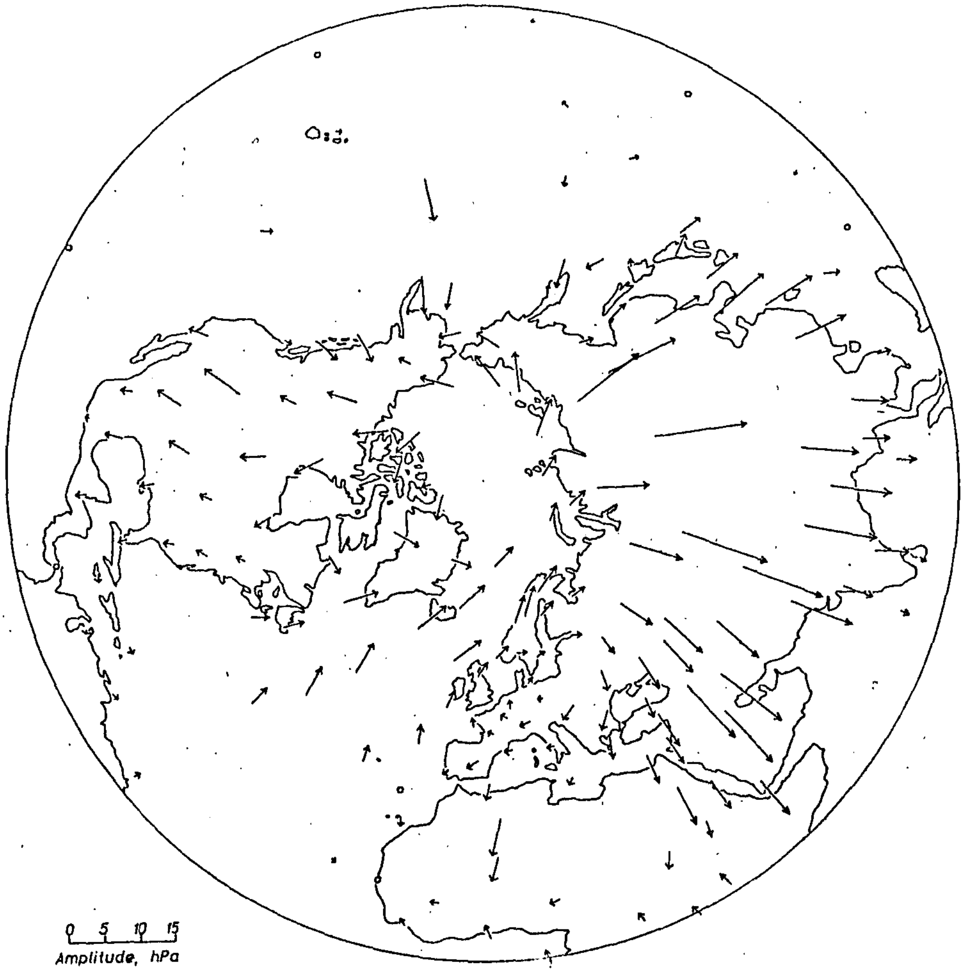


Fig. 3a Amplitude and phase of the annual cycle of sea-level pressure, Northern Hemisphere

minimum is late in the autumn; 3. and with the *arctic* and *subarctic types*, the maximum occurs in April or May, the minimum in January or February, with a secondary maximum in November. The HAHN and SÜRING's classification system, which was mainly based on the data of northern hemispheric stations, has essentially been verified by the latest descriptions, too.

Comparing the middle-latitude regions of the oceans, as well as the polar areas of the Southern Hemisphere with the zone between the latitude 50°S and the Antarctic coastal district, the semi-annual cycle shows an opposite phase in the annual course of air pressure. This phenomenon, which is well reflected in our data as well (*Figs. 2a, b*), has already been described by several authors (e.g. VOWINCKEL, 1955a, 1955b; SCHWERDTFEGER and PROHASKA, 1956; HSU and WALLACE, 1976). In monthly mean sea level-pressure time series interpolated to grid points, HSU and WALLACE (1976) have analysed the global distribution of the annual and semi-annual cycles, and published them in a vectorial form.

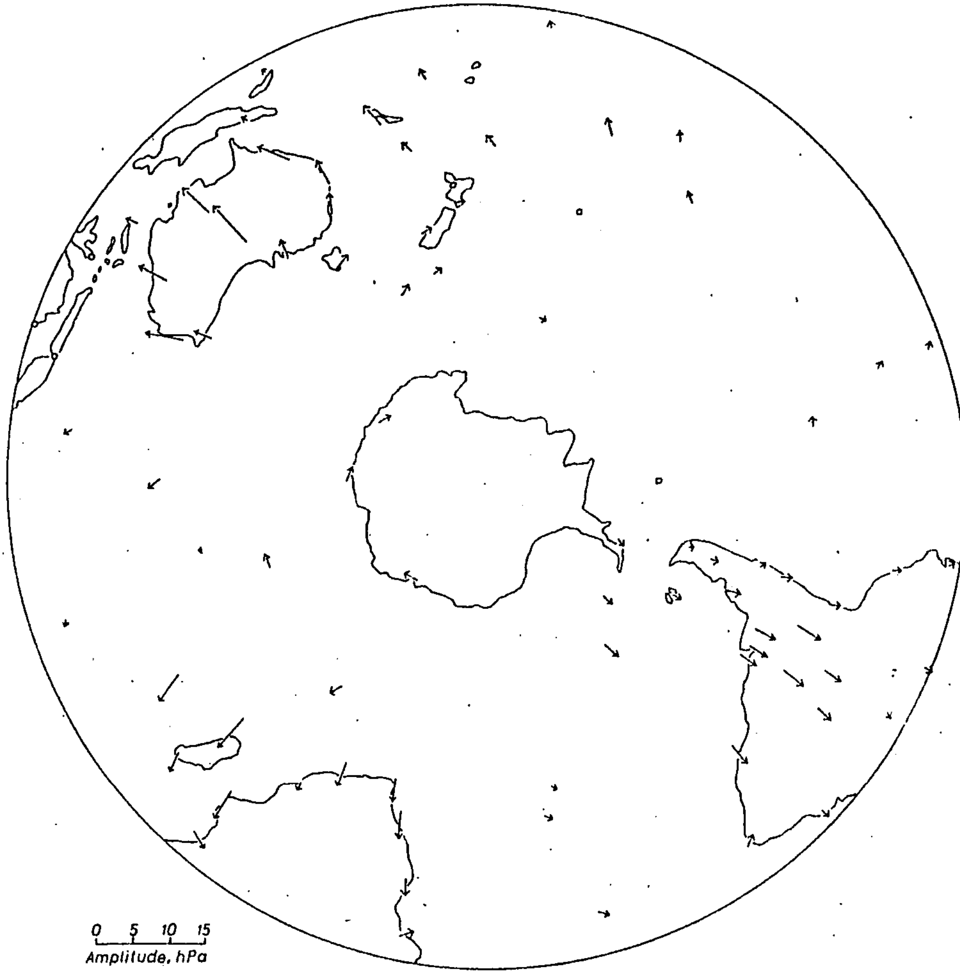


Fig. 3b Amplitude and phase of the annual cycle of sea-level pressure, Southern Hemisphere

After removing the linear trends, sea-level pressure time series of each station have been subjected to a harmonic analysis. The method has already been described by a number of authors. Among them *HAMED et al. (1986)* offer a very clear and concise survey of the harmonic analysis. For deciding the reality of an amplitude belonging to a definite length of period, the same authors *(HAMED et al., 1987)* give such limits - by the aid of the Monte Carlo method - that the probability of amplitudes greater than these limits is already very little: *10, 5,* or *1 %.* In our procedure of decision the significance of the amplitudes haves been found on the basis of these limits.

The amplitudes and phases have been plotted in a vectorial form *(Figs. 3-4)*, where the length of the arrows indicates the amplitude of the yearly cycle, and the direction shows the phase. When plotting, the midpoint of the amplitude length belonging to the given station (or rather to its pressure time series) gets onto the geographical coordinates of the

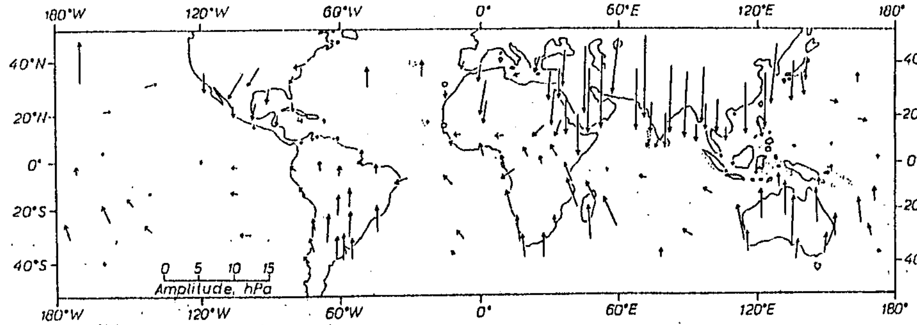


Fig. 3c Amplitude and phase of the annual cycle of sea-level pressure , 40° N - 40° S

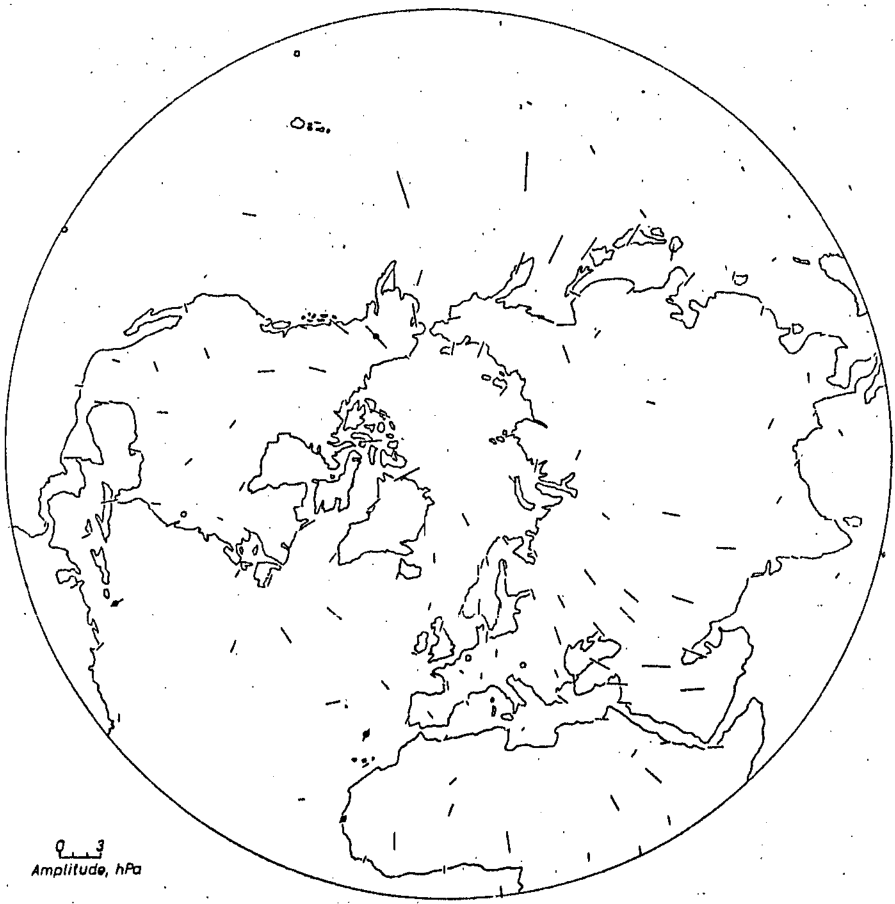


Fig. 4a Amplitude and phase of the semi-annual cycle of sea-level pressure, Northern Hemisphere

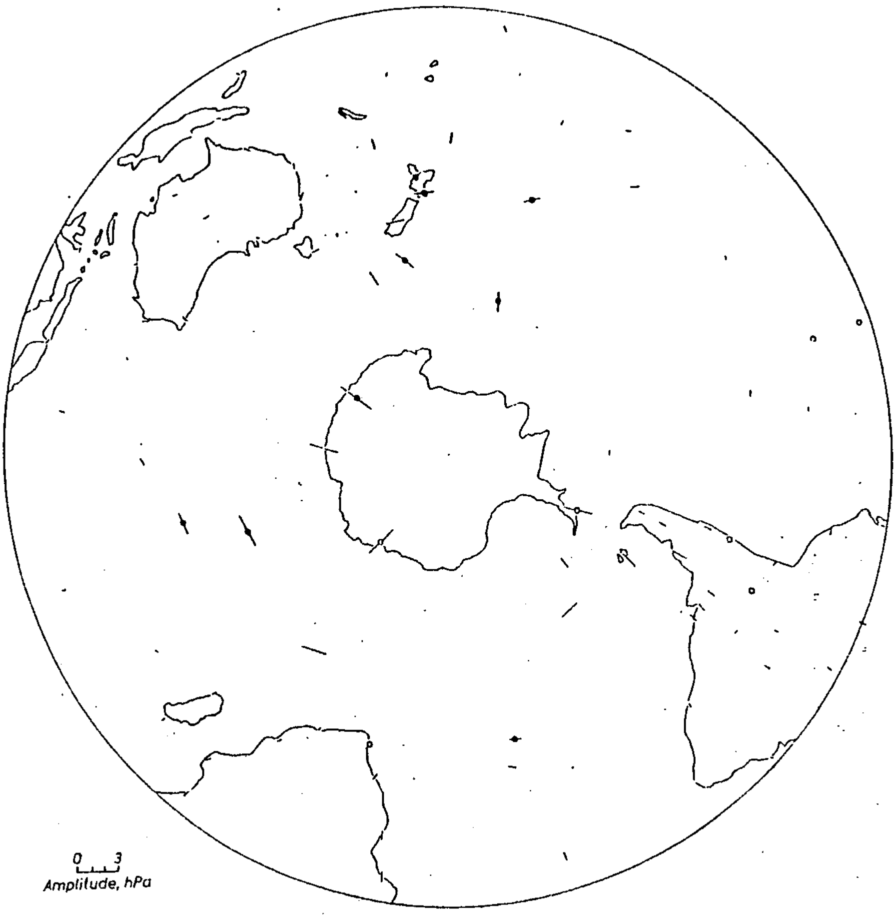


Fig. 4b Amplitude and phase of the semi-annual cycle of sea-level pressure, Southern Hemisphere

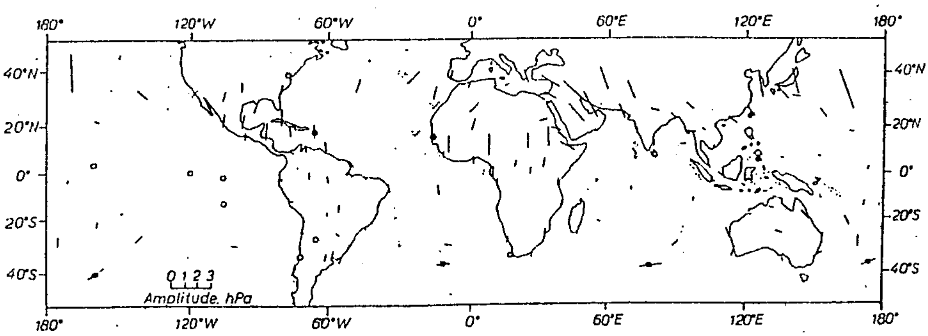


Fig. 4c Amplitude and phase of the semi-annual cycle of sea-level pressure, 40° N - 40° S

station. The interpretation of the phase is as follows. If an arrow points from the north towards the south, it indicates maximum in the annual cycle on 1 January; if it points from the east towards the west, it indicates maximum on 1 April, etc.. Thus the arrows revolve clockwise, about $1°$ daily. It must be remarked that with this phase interpretation an arrow which points from the north towards the south indicates in the Northern Hemisphere a winter maximum, at the same time it shows in the Southern Hemisphere a summer maximum, etc.. The interpretation of the phase is the same for the semi-annual cycle, with the limitation that in the extreme points of the vectors there are no arrows. If, in this way, a vector shows in north-south direction, this indicates a semi-annual cycle the maximums of which are on 1 January and on 1 July; if it shows in east-west direction, then maximums occur on 1 April and on 1 October, etc.. This interpretation has been applied after HSU and WALLACE (1976).

The amplitudes and phases of the annual cycle can be seen in *Fig. 3*, while those of the semi-annual cycle are shown in *Fig. 4*. (Supplements. *Figs. 3a, b*: the amplitudes smaller than *0.5 hPa* are denoted by empty circles. *Fig. 3c*: the amplitudes smaller than *0.2 hPa* are denoted by empty circles. *Figs. 4a, b, c*: the amplitudes smaller than *0.1 hPa* are denoted by empty circles. The stations at which the second harmonic of the annual cycle is greater than the first harmonic, are shown by thick circles.)

On the basis of these *Figs. 3-4* the establishments are as follows:

- The *continental type* described by HANN and SÜRING (1939) is characteristic over all the continents, in subtropical and temperate latitudes of both hemispheres.

- HANN and SÜRING's *oceanic type* can be shown only for the oceans of subtropical and temperate latitudes of the Northern Hemisphere. A tendency from the maximum of late autumn to that of the winter can be observed over the subtropical oceans of the Southern Hemisphere, where the amplitudes of the annual cycle are considerably smaller than over the neighbouring continents.

- Over the *polar areas of the Northern Hemisphere* it is the tendency of a maximum late in summer that can be seen in the annual cycle, in contradiction to the HANN and SÜRING's conclusion, as well as to the conclusiom of HSU and WALLACE (1976), who have established here a tendency to a spring maximum.

- Over the *Southern Hemisphere's oceans of temperate latitudes* as well as over the *Antarctic coastal region* a characteristic semi-annual oscillation can be observed. Between the latitudes *40°* and *50°S*, at the time of the equinoxes a tendency referring to a maximum can be found, while south of the latitude *60°S* maximums occur in the periods near the solstices. This semi-annual oscillation of different phases, taking place between the temperate and higher latitudes of the Southern Hemisphere had already been pointed out by a number of researchers previously, as we have already referred to this in what has gone before. (Although the network of stations is extraordinarily sparse in this area, yet it is sufficient for us to point out this phenomenon over most of the Southern Hemisphere's area mentioned above.)

Our results - apart from the third establishment - show good agreement with the HANN and SÜRING's results (1939), as well as with the HSU and WALLACE's conclusions (1976).

The statistical significances of both the annual and the semi-annual cycles of sea-level pressure, as well as those of all the other periodic component waves have been investigated station by station. The investigation referred to *n/2-1* component waves at each stations - from the *2nd* to the *(n/2)nd* periodic component - where *n* is the number of the elements in the sample. (The number of the monthly mean sea-level pressure values in the period taken into consideration.)

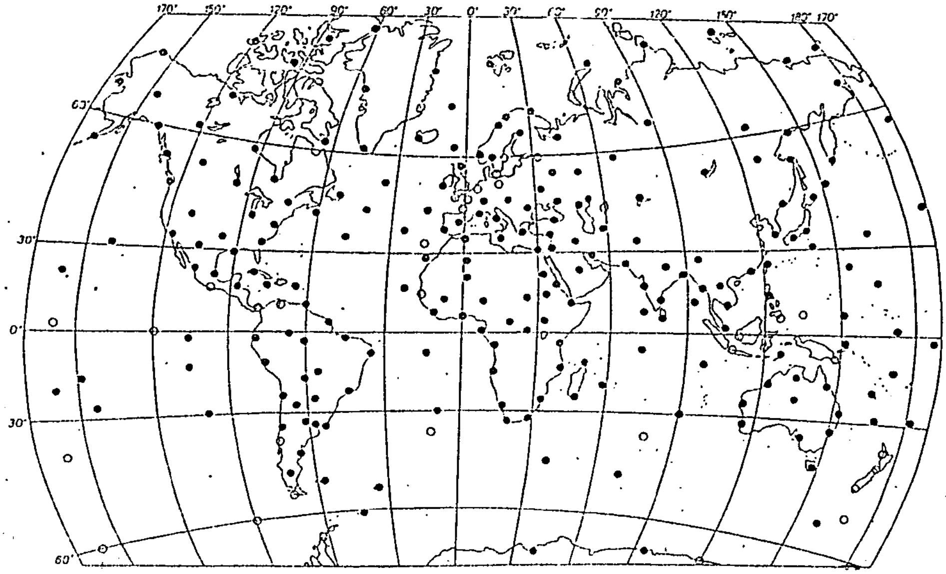


Fig. 5a The 12 monthly cycle of sea-level pressure, by stations;
● = significant, ○ = not significant

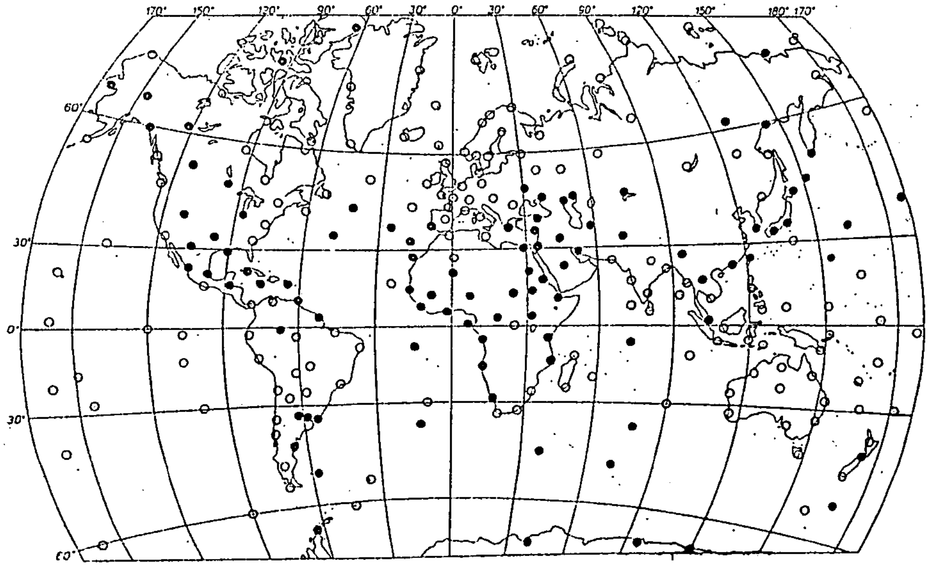


Fig. 5b The 6 monthly cycle of sea-level pressure, by stations;
● = significant, ○ = not significant

The annual cycle was not characteristic only with *13.4* % of the stations. The areas of these are in the southern basin of the Pacific Ocean, in the regions of Indonesia and Central America, as well as in Western Europe and the Baltic countries (*Fig. 5a*). The semi-annual cycle is not to be found in *30.1* % of the stations. It is not shown at all in the whole basin of the Pacific Ocean, in Europe, the polar regions of the Northern Hemisphere, Australia, the Indian subcontinent, and in a considerable part of South America (*Fig. 5b*). Significant periodicities of *11* and *13* months have been found in *19.4* % of all stations. These are parts of the annual cycle, and so they cannot be considered to be completely independent of that. The *14*-month period was statistically significant in 2 cases, the *4*-month one in *6*, the *2*-month one in *4* cases; other periods were statistically real on *1* occasion each, altogether in 7 cases, that is the periods mentioned above were only significant altogether in *6.9* % of the stations examined. On the basis of these results it can generally be established that in the temporal course of global sea-level pressure there exist only two kinds of cycles: the characteristic *12-month*, and the less marked *6-month* one. There is no other periodicity. Consequently, the great number of, and rather different, periods pointed out in the temporal course of sea-level pressure, and considered to be statistically significant by numerous authors, are probably not real ones. The most frequently searched periods – the *11*-year sunspot cycle, the tropospheric quasi-biennial (mostly *26*-month) oscillation, and the Southern Oscillation – are not reflected in the temporal course of sea-level pressure.

References

AMELUNG, U., 1962: Die dritteljährliche Luftdruckwelle auf der Nordhalbkugel und höhere Harmonische. - Archives for Meteorology, Geophysics and Bioclimatology. Ser. A., *13*(2), pp.241-262.

ANGELL, J.K. - KORSHOVER, J., 1968: Additional evidence for quasi-biennial variations in tropospheric parameters. - Mon. Wea. Rev., 96., pp.770-784.

BERKES, Z., 1968: Jährliche Veränderung der atlantisch-europaischen Luftdruckverteilung. - Időjárás, 72., pp.330-340.

BHALME, H.N. - JADHAV, S.K., 1983: Major quasi-periodic fluctuations in the drought indices. - Archives for Meteorology, Geophysics and Bioclimatology, 32(3/2), pp.309-317.

FU, CONG-BIN, 1979: On the variation of mean meridional circulation related with long-range weather processes. - Acta Meteorologica Sinica, Beijing, 37., pp.74-85.

HAMED, A.F. - GULYAS, O. -KETSKEMETY, L., 1986: Meteorológiai idősorok periodicitásának elemzése. I. (Analysis of periodicities of meteorological time arrays. I.) - Időjárás, *90*., pp.14-23.

HAMED, A.F. - SZENTIMREI, T. - GULYAS, O., 1987: Meteorológiai idősorok periodicitásának elemzése. II. (Analysis of periodicities of meteorological time arrays. II.) - Időjárás, *92*., pp.38-45.

HSÜ, CHIN-PING, F. - WALLACE, J.M., 1976: The global distribution of the annual and semiannual cycles in sea level pressure. - Mon. Wea. Rev., *104*., pp.1597-1601.

KAUFELD, L., 1972: Das globale Luftdruckfeld in Seehöhe. - Berichte des Deutschen Wetterdienstes. Bd. *17*., Nr. 129., Offenbach a. M.

KHANINOV, H.A., 1966.,: O nekotorykh zakonomernostakh mnogoletnykh izmeneniy atmosfernogo davleniya v uznom

LANDSBERG, H.E. et al., 1966: Spectrum and cross-spectrum analysis of atmospheric pressure and pressure gradients of the North Atlantic area.- Research and Development Report. U.S.National Weather Records Center, Asheville, N.C., No. *16.*, 26.p.

LOGINOV, V.F. - SUKHOMOZOVA, G.I., 1972: Vozmozhnaya priroda nekotorykh tsiklicheskikh sostavlyayushshikh v atmosfernom davlenii. - Geograficheskoe Obshshestvo SSSR, Izvestiya, *104.*, pp.213-217.

MICHELCHEN, N., 1981: Estimates of large-scale atmospheric pressure variations in the upwelling are of northwest Africa. - In: IDOE International Symposium on Coastal upwelling. Univ. of Southern C.A., Los Angeles, 1980. Coastal upwelling. American Geophysical Union, Washington, D.C., pp.17-20.

PECZELY, G., 1978: Fluctuation of precipitation in the Tropical Zone of the Pacific. - Időjárás, *82.*, pp.1-16.

SCHONWIESE, C.D., 1969: Spektrale Varianzanalyse klimatologischer Reihen im longperiodischen Bereich. - Wissenschaftliche Mitteilungen, München Universität, Meteorologisches Institut, No. *15.*, 81.p.

SCHONWIESE, C.D., 1971: Klimaanalyse mittels Varianzspektrum und numerischer Bandpassfilterung.- Wissenschaftliche Mitteilungen, München Universität, Meteorologisches Institut, No. *21.*, pp.62-63.

SCHWERDTFEGER, W. - PROHASKA, F., 1956: Der Jahresgang des Luftdrucks auf der Erde und seine halbjährige Komponente. - Meteor. Rund., 9., pp.33-43.

von HANN, J. - SURING, R., 1939: Lehrbuch der Meteorologie. - 4th ed., Leipzig.

VOWINCKEL, E., 1955a: Southern Hemisphere Weather Map Analysis: Five-year mean pressure. Part I. South Africa, Weather Bureau, Notos, vol. 4., pp.17-50.

VOWINCKEL, E., 1955b: Southern Hemisphere Weather Map Analysi Five-year mean pressure. Part II. South Africa, Weather Bureau, Notos, vol. 4., pp.204-216.

WAGNER, A.J., 1971: Long-period variation in seasonal sea-level pressure over the Northern Hemisphere. - Mon. Wea. Rew., 99., pp.49-66.

WANG, SHAO-WO, 1963: A preliminary study on the characteristic and evolution of mean monthly circulation. Pt. 1. Zonal Index. - Acta Meteorologica Sinica, Beijing, 33., pp.361-374.

DIE WITTERUNG IN UBERSEE, 1958-1980. Deutscher Wetteramt, Hamburg.

MONTHLY CLIMATIC DATA FOR THE WORLD, 1961-1980. - National Climatic Center, Asheville, N.C. USA.

WORLD WEATHER RECORDS, 1951-1960. vol. 1-6., Washington, D.C. 1965.
1961-1970. vol. 1-6., Asheville, 1979.

SOLAR ENERGY MAPPING

by

I. Tózsa and *L. Pelle*

Napenergia térképezés. A dolgozat a direkt sugárzás tenyész időszakban érkező hőenergiája eloszlásának számításával foglalkozik. Az érkező hőenergia eloszlása adott földrajzi szélességű hegyi terepen a lejtő szögétől és dőlésirányától függ. Ennek az eloszlásnak térképes ábrázolása elősegítheti a művelési rendszerek tervezését Magyarország hegyvidéki mezőgazdasági területein.

This paper is a brief information on computing heat from direct solar radiation during the growing season. The distribution of incidenting heat depends on the inclination and exposure of slopes in a hill region of a given latitude. A map showing this distribution can contribute to the re-designing of cropland pattern of hill agricultural areas in Hungary.

Agrogeographical research is one of the recently developed branches of landscape study in Hungary. It surveys and assesses the effects of physical geographical factors on crop cultivation. Its aim is to produce some kind of a cropland pattern map showing the order of preference of different plants on the basis of physical environmental endowments. These cropland pattern maps could be then directly applied by state farms and agricultural cooperatives.

Unlike the quantity of solar radiation in the growing season, unfavourable soil, precipitation and even topographic endowments can be at least theoretically - improved over large areas (consider amelioration, irrigation, reclamation and strip cultivation, etc). Consequently, wedecided to construct a method for mapping solar radiation heat to enable agricultural farms on hilly terrains to adjust their field boundaries to the amount of heat received complying with the requirements of plants.

The basic idea we used is extremely simple. We superposed the slope exposure (*Fig. 1*) and slope angle (*Fig. 2*) maps of the same area. The resulting mosaic map shows an areal distribution of heat (*Fig. 3*). The slope exposure has *8* categories (*N,W,S,E,NW,SW,SE,NE*). The slope category map - as usual in Hungarian agricultural application - has the following classes: *5-12°, 12-17°, 17-25°, 25°< and the flat surface 5°>*. Thus, besides constructing slope exposure and angle maps we need a table showing radiation heat for each of the $8 \times 4 + 1$ topographic conditions. Using the so called "cloud filter" factor we can compare the heat requirement of a plant during the growing season and the mosaic map showing the areal distribution of heat.

The mountain we chose as an example is found in *West Transdanubia*. *Mount Somló* is *432* metres high, built up of basaltic rocks and famous for its vineyards and grape vine plantations. The algorithm for computing the heat distribution table is described below.

Solar constant: $I_o = 1354\ W.m^{-2}$ at a mean Sun-Earth distance

$$l = \frac{\text{actual Sun-Earth distance}}{\text{mean Sun-Earth distance}} \quad \text{given for each day}$$

q = complex transmissivity coefficient of the atmosphere ($q = 0.93$)
A = opacity factor of the atmosphere (eg. $A = 3.5$)
h = Sun's elevation angle
= latitude
t = Sun's hour-angle
t_o = Sun's hour-angle at sunset ($-t_o$ = sun hour-angle at sunrise)

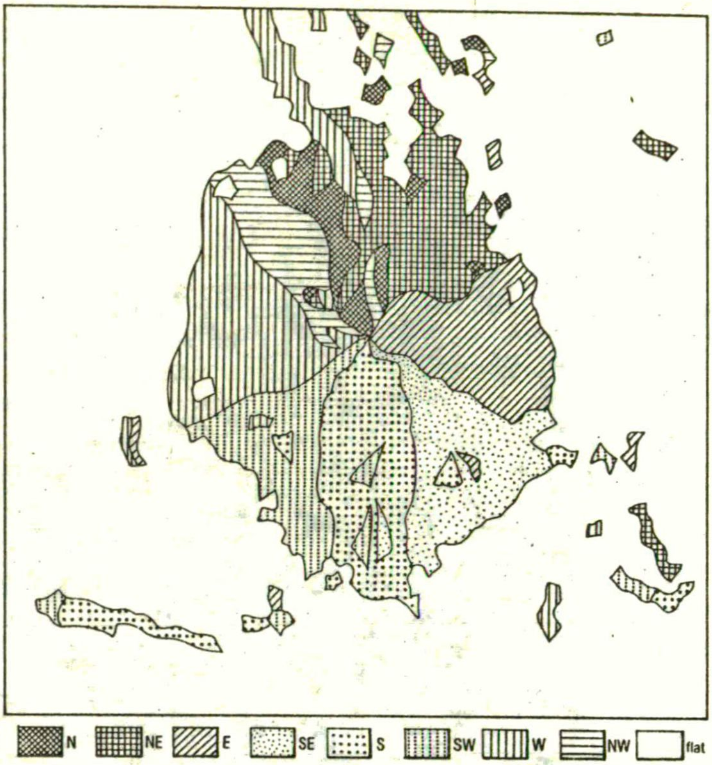


Fig. 1. Slope exposure map of Mt.Somló

Knowing the Sun's elevation angle in hour-angle function is:

$$\sin h = \sin \varphi . \sin \delta + \cos \varphi . \cos \delta . \cos t \qquad /1/$$

Hence the hour-angle of sunset ($h = 0$):

$$\cos t_{o} = -tg \varphi . tg \delta \qquad /2/$$

a = Sun's azimuth

The relationship between azimuth and hour-angle:

$$ctg\, a = \frac{\sin \varphi . \cos t - tg \delta . \cos \varphi}{\sin t}$$

$$a = arc\, ctg \frac{\sin \varphi . \cos t - tg \delta . \cos \varphi}{\sin t} \qquad /3/$$

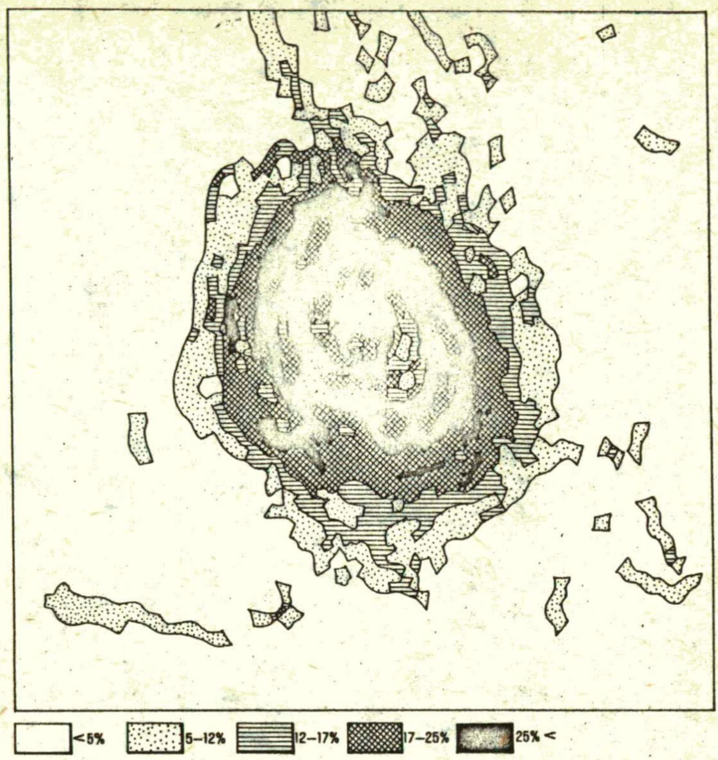


Fig. 2. Slope categories of Mt.Somló

a_1 = slope azimuth (exposure)
i = slope angle (inclination)
z = path of solar radiation in the atmosphere

$$z = \begin{cases} 39.7 \exp(-0.315\ h) & \text{if } 0° < h =< 3° \\ 1^{-\sin h} - 66.6\ h^{-2.58} & \text{if } 3° < h =< 8° \\ 1^{-\sin h} - 161.8\ h^{-3.02} & \text{if } 8° < h =< 35° \\ 1^{-\sin h} & \text{if } h > 35° \end{cases}$$

Direct radiation onto a horizontal flat surface (I_r) in a particular case:

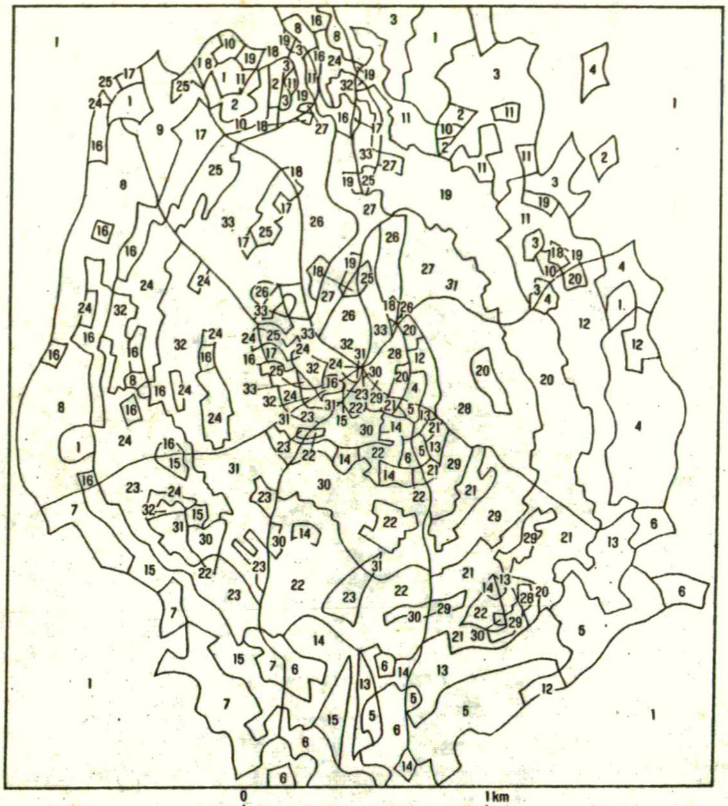
$$I_r = I_o . l^{-2} . q^{Az} . \sin h \qquad /5/$$

Let us transfer the value of the solar constant from *s* into radian:

$$C = (86400/2\ \ ).1354\ W.m^{-2} = 18618836\ W.m^{-2} = 18.62\ MW.m^{-2} \qquad /6/$$

Direct radiation received by a sloping surface (I_s) at a given moment:

$$I_s = I_o . l^{-2} . q^{Az} . [\sin h . \cos i + \cos h . \sin i . \cos (a - a_1)] \qquad /7/$$



Slope angle	flat	EXPOSURE							
		N	NE	E	SE	S	SW	W	NW
< 5%	1	–	–	–	–	–	–	–	–
5–12%	–	2	3	4	5	6	7	8	9
12–17%	–	10	11	12	13	14	15	16	17
17–25%	–	18	19	20	21	22	23	24	25
25% <	–	26	27	28	29	30	31	32	33

Fig. 3 Heat distribution map of Mt. Somló

S = sum of daily radiation

Sum of daily radiation can be obtained by the integration of the function describing radiation in a particular case from sunrise to sunset:

$$S = C.I^{-2} \quad q^{A*} \, [\sin h.\cos i + \cos h.\sin i.\cos (a-a_i)].dt \qquad /8/$$

- the variables are expressed by (z, m, a); it can be solved by /1/, /3/, /4/.
- integration limits can be calculated from /2/.
- value of C constant is given in /6/.
- value of is given for each day and may be regarded as a constant for each day.

These formulas of the above algorithm allow the automated computation of direct solar radiation heat received by 33 types of terrain (with varying exposure and angle) for each day of the growning season (183 days on the average in Hungary).

References

JUSTYAK, J. - ERDOS, K., 1979: A domborzatnak és a napsugárzásnak mint termőhelyi tényezőknek alakulása a Bodrogkereszturi-félmedencében (The tendency of relief and solar radiation changes - as natural factors - in the Bodrogkeresztur half-basin). - Földrajzi Ertesitő *28.*, 3-4., pp.249-266.

JUSTYAK, J. - TAR, K.; 1974: A keleti és a nyugati lejtőre és a vizszintes felszinre jutó közvetlen sugárzás kapcsolata (Relationship between direct radiation on eastern and western slopes and horizontal flat surfaces). - Időjárás *78.*, 4., pp.228-234.

MESZAROS, I. - PROBALD, F., 1968: Lejtőtulajdonságok hatása a közvetlen besugárzás mennyiségi eloszlására (Effect of slope properties on the quantitative distribution of direct solar radiation). - Földrajzi Ertesitő *17.*, 2., pp.249-256.

PECZELY, G., 1979: Eghajlattan (Climatology). - Tankönyvkiadó, Budapest.

COMPARING THE ANNUAL COURSE OF THUNDERSTORM FREQUENCY IN HUNGARY WITH DATA OBTAINED A HUNDRED YEARS AGO

by

Maria Szentpeteri

JUHASZ GYULA TANARKEPZO FOISKOLA, SZEGED

To the memory of Professor Peczely

A magyarországi zivatargyakoriság évi eloszlásának 100 évvel ezelőtt nyert adatokkal történő összehasonlítása. Az *1968-77*-es évek adatai szerint mutatkozó magyarországi zivatargyakoriság évi menete és a közel *100* évvel ezelőtt kapott, *Héjas E.* által közölt eredmények között főbb vonásaiban nincs nagy különbség (lásd az *1.*, *2.*, és *3.* ábrákat!). Úgy tűnik, hogy az általam készített statisztikához használt adatok talán megbízhatóbbak, vagyis a jelenkori "zivatarmérés" szubjektív hibája mintha kisebb lenne, mint a 100 évvel ezelőttié. Talán ez lehet az egyik oka annak, hogy a 33. dekád körül egy kis lokális maximumot találtam. *Héjas E.* azon következtetése, miszerint "a zivatargyakoriság maximuma megelőzi a hőmérséklet júliusra eső maximumát", az 1968-77-es adatok tükrében nem teljesül.

In the main features there is not much difference between the annual course of the thunderstorm frequency in Hungary obtained from the data of the years *1968-77* and the results published by *E. Héjas* nearly a hundred years ago (see Figs. *1*, *2* and *3*). It seems that the recent data are more reliable, as if the subjective error of present-day "thunderstorm measurement" is less than the earlier one taken *100* years ago. Perhaps this may be the reason for the fact that I found a small local maximum about the 33rd decade. *E. Héjas*'s conclusion that "the maximum of thunderstorm frequency precedes the maximum of temperature in July" is not proved in the light of the 1968-77 data.

During the past hundred years, the intensive studying of the annual course of the phenomena of atmospheric electricity has, for certain reasons, fallen into the background. Probably these circumstances explain that relating to the above problem one can only find approaching reports at most, even in the university text-books. In connection with the annual course of the thunderstorm frequency in Hungary - nearly one hundred years ago - *ENDRE HEJAS* reported rather reliable data. In his book, published in *1898* [*1*], he precisely examined the atmospheric pressure, the wind, the temperature, the vapour pressure and the relative humidity, the cloudiness, the evaporation, the ozone and finally the precipitation on stormy days.

In his examinations he took into consideration what kind of correlation is between storminess and weather situation, and which are those types of weather that lead to the intense developing of thunderstorms. After the satisfactory critical elaboration of data the collected from the territory of the country of that time *E. Héjas* drew several conclusions which are worth reviving and comparing with the data of today.

During statistical examinations it often occurs that the figures of the elements of the samples selected for the evaluation are not the same. In such cases, frequency distributions cannot be directly compared; this is why some sort of mathematical method must be applied to be able to directly compare the distributions. Since the number of the stations examined by me, and that *of E. Héjas*'s stations differ, I transformed *E. Héjas*'s monthly frequency values to the percentage of the annual frequency; so the obtained values (as relative frequencies) are independent from the number of the stations; so there is a possibility of direct comparison. I compared the obtained results to the data counted from the data of the years 1968-77 [2]. This is demonstrated by *Fig. 1*. *E. Héjas*'s results are taken from the tables of pages *108* and *109* of his book. However, I should like to remark that the title writing of the tables is not correct. It is probable that

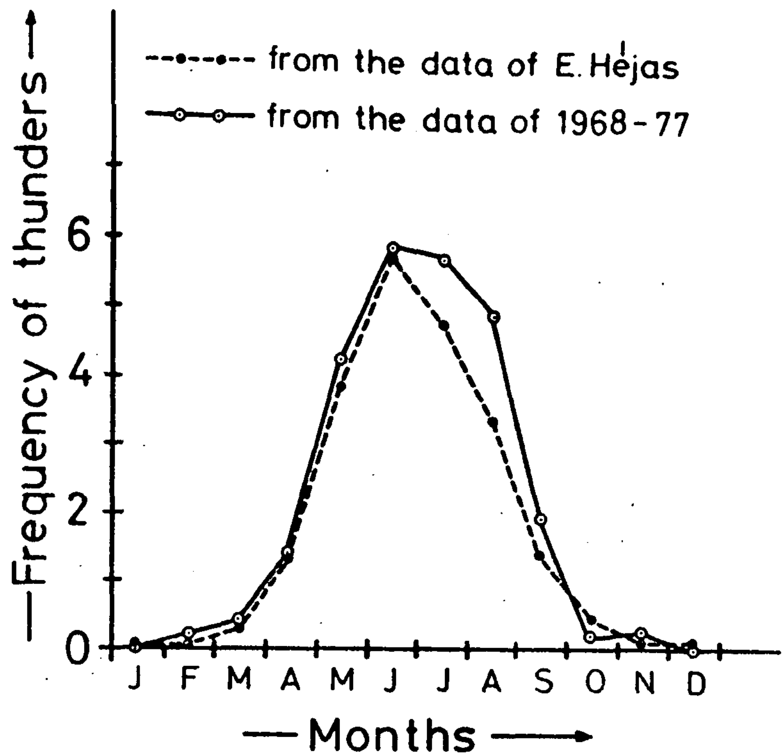


Fig. 1 Annual course of thunderstorms in Hungary in monthly frequencies

E. Héjas mixed the numbers of the thunderstorms with the numbers of the stormy days. For in his table he does not give the monthly and annual sums of the stormy days - as he writes in the title of his table - but the monthly and annual sums of the detected thunderstorms.

E. Héjas also offers further possibility for comparison by having studied the annual course of thunderstorm frequency in taking them to pentads. Among his conclusions, I should like to emphasize that he experienced a decline about the 35^{th} pentad. He brought this into connection with the fact that in the 25-year annual course of temperature there is a well recognizable decline about the 35^{th} pentad. Recognizing of such coincidences is very important, but we have to consider the fact that the mere coincidence is not a reason for us to conclude with absolute certainty that there is a relation of cause and effect between the two variables. For in such cases it often came to light that the two variables depend on the changing of a third (possibly several other) variable(s).

It evidently means that it would be unwise to speak about the fact that the cause of the changing of one variable is the changing of the other one. The above-mentioned decline can be shown on the basis of the *1968-77* data [2]. Since the frequency fluctuations are relatively great in the distribution of pentadic breaking down, so I converted *E. Héjas*'s data into units of ten days (decades), and compared to the decadal distribution counted from the data of the years 1968-77. In order to demonstrate the course of the two distributions, I drew the two distribution "curves" as equally high (by dividing them with the maximum values). It can be seen in

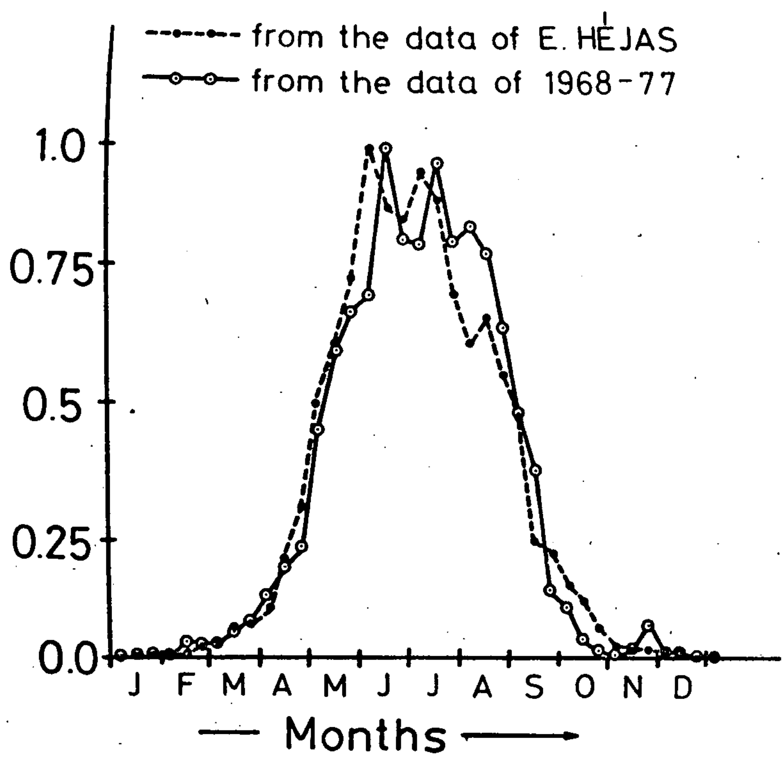


Fig. 2 Annual course of thunderstorms in decadal frequencies (unit = maximal decadal frequency)

the figure that the courses of the two "curves" are almost the same. The above-mentioned decline at the *35th* pentad or *17-18th* decade, which still exists in the case of *15*-day intervals but is no longer so expressed, is recognizable at both distributions, and in the case of a monthly course, it disappears already. In connection with the *2nd figure*, I should like to draw the attention to the fact as well that on the basis of the data of the years 1968-77, at the time of the minor (*5*-, *10*-,or *15*-day) course demonstration toward the end of November (at about the *33rd* pentad) a little local maximum is also recognizable [2].

Further examinations can be done also because there are a couple of stations among those of *E. Héjas* which occur among the stations examined by me, as well. These data are summarized in *Table 1*. It can be seen that, on the one hand, the average number of the thunderstorms is *22.4* for the stations listed by *E. Héjas*; on the other hand, in my statistic the number is *25.02*. The question emerges whether the two data series of *Table 1*, more precisely the two mean values, can be considered significantly different or not. The answer is *NO*. On fulfilling the two-model *t-proof*, it is obtained that the difference between the two values cannot be considered significant even in the case of *10 %* confidency level. This means that the values of *22.4* and *25.02* are practically equal. It is immediately understandable from the fact that in Hungary the standard deviation of thunderstorm frequencies is roughly *3* for one station [2]. For the stations in *Table 1*, so for *Budapest, Eger, Nyíregyháza, Kalocsa and Szeged*, *E. Héjas* gave, beside the annual number of the thunderstorms, even the average monthly thunderstorm

Table 1

The annual sums of thunderstorm frequencies for 12 stations on the basis of the data of *E. Héjas* and of the years 1968-77

Stations	*E. Héjas*'s data	Data of the years 1968-77
Budapest	19.2	18.9
Eger	23.3	25.5
Kalocsa	*21.0*	18.8
Keszthely	23.9	27.5
Komárom	19.2	22.5
Makó	23.0	14.3
Mezöhegyes	20.8	27.6
Nyiregyháza	*24.6*	30.0
Sopron	20.9	27.0
Szeged	*21.6*	32.7
Szolnok	24.4	28.7
Zalaegerszeg	27.2	28.8
Sum total	269.1	302.3
Average for one station	22.4	25.2

The italicized values are arithmetical means of two data published by *E. Héjas*

Table 2

Annual course of thunderstorm distribution with monthly frequencies for 5 stations. Among the data-pairs the first one is always of *E. Héjas*, the second is of 1968-77

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Budapest	0.00	0.04	0.32	1.20	3.92	5.12	3.76	3.20	1.16	0.40	0.00	0.04
(Szabadság-hegy)	0.00	0.40	0.20	1.10	2.80	4.20	3.80	4.40	1.80	0.00	0.20	0.00
Eger	0.05	0.09	0.35	1.61	4.48	6.26	5.18	3.52	1.30	0.30	0.13	0.00
	0.00	0.10	0.50	1.50	3.80	6.40	6.70	4.40	1.70	0.10	0.30	0.00
Nyiregyháza	0.00	0.12	0.42	1.42	3.88	6.79	5.87	3.71	1.13	0.29	0.04	0.00
	0.00	0.20	0.20	1.50	5.90	6.80	7.30	5.10	2.50	0.40	0.10	0.00
Kalocsa	0.00	0.05	0.19	1.00	3.33	5.19	4.62	3.52	1.43	0.62	0.10	0.00
	0.00	0.30	0.40	1.30	2.70	4.40	4.00	3.60	1.70	0.20	0.20	0.00
Szeged	0.09	0.00	0.30	1.70	3.78	3.53	4.35	2.74	1.96	0.65	0.17	0.04
	0.00	0.00	0.80	1.60	6.10	7.60	6.70	7.10	2.00	0.30	0.50	0.00
Average for one station	0.03	0.06	0.32	1.39	3.88	5.74	4.76	3.34	1.40	0.45	0.09	0.02
	0.00	0.20	0.42	1.40	4.26	5.88	5.70	4.92	1.94	0.20	0.26	0.00

Annual sum for one station 21.46
25.18

frequencies. The data used for the annual period are summarised in *Table 2.* The difference between the two distributions can be seen in *Fig. 3.* Here the most apparent thing is that the distribution counted from *E. Héjas*'s data is sharper to the left than the distribution obtained from the data of the years 1968-77. This fact can be observed in *Fig. 1*, and even in *Fig. 2.* From this shift to the left *E. Héjas* concluded - wrongly in my opinion - that "*The majority of our thunderstorms come in early summer, and so the maximum of thunderstorm frequency precedes the maximum of temperature coming in July*". According to *E. Héjas*'s statistics, the number of thunderstorms for one station in Hungary is *22.2.* He himself considered this value only a lower approaching because at several stations only the strongest thunderstorms could be recorded, the farther ones were not taken into consideration. He chose *1.5* as tolerance in the number of thunderstorms (he did not give any reason for his choice). In the chapter "Thunderstorm Statistics", it was average values as about *25* and *26* average value - instead of the above-mentioned number of thunderstorms - which he considered to be the most probable estimated values. These latter values correspond very well with the average values obtained on the basis of the 1968-77 data [2]. *E. Héjas* gives *19.2* thunderstorms annually for the northern slope of *Várhegy* in Budapest, and this is almost equal to the mean value of *18.9* of station on *Szabadsághegy* obtained on the basis of the data of the years 1968-77. In [3,4] I have dealt in greater detail with the identities and differences relating to the spatial distribution of the thunderstorm frequency in Hungary, a swell as to the annual courses of the fulguration and hail frequencies. In the main features there is not a great difference

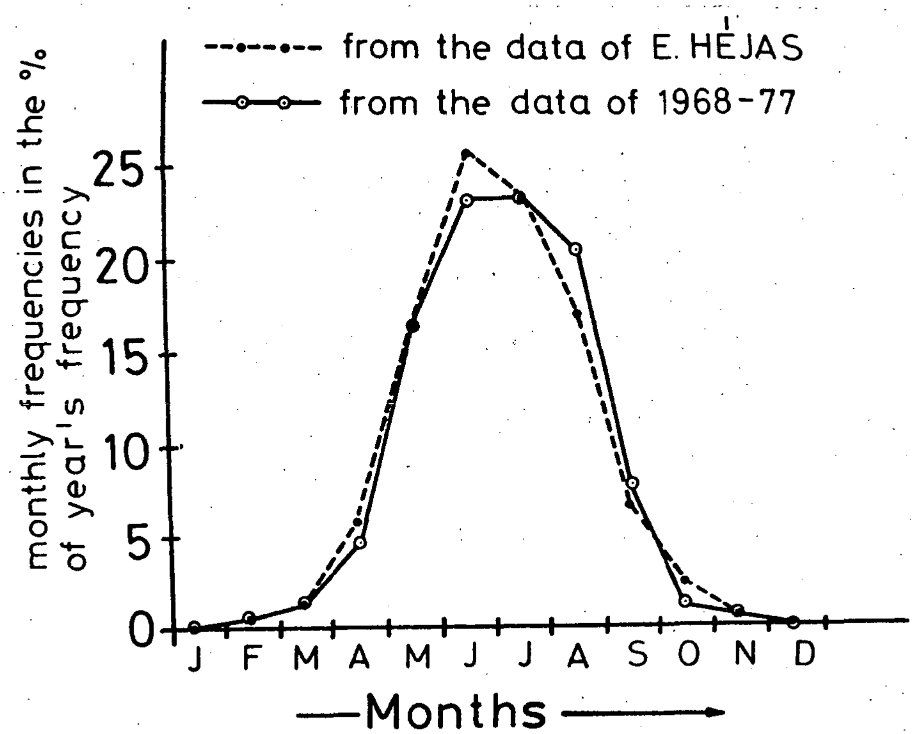


Fig. 3 Annual distribution of thunderstorms on the basis of the data from the towns of Budapest, Eger, Nyíregyháza, Kalocsa and Szeged in monthly frequencies

between the annual course of thunderstorm frequency in Hungary obtained from the data of the years 1968–77 and the results obtained by *E. Héjas* nearly *100* years ago (see *Figs. 1, 2* and *3*).

It seems that the data used for my statistics are perhaps more reliable; that is, it seems as if the subjective mistake was smaller in present day "thunderstorm measuring" than in the one 100 years ago. Perhaps this may be one of the reasons for the fact that I found a small local maximum around the *33rd* decade. *E. Héjas*'s conclusion that "the maximum of thunderstorm frequency precedes the maximum of temperature, falling in July" is not confirmed by the data from 1968–77.

References

[1] *E. HEJAS*: A zivatarok Magyarországon az 1871-től 1895-ig terjedő megfigyelések alapján. (Thunderstorms in Hungary on the basis of the observations extending from 1871 to 1895).- Budapest, 1898.

[2] *M. SZENTPETERI*: A zivatargyakoriság évi menete Magyarországon. (The annual course of thunderstorm frequencies in Hungary.) - Juhász Gyula Tanárképző Főiskola Tudományos Közleményei, Szeged, 1982. 95-104.

[3] *M. SZENTPETERI*: A zivatargyakoriság területi eloszlása Magyarországon. (The regional distribution of thunderstorm frequency in Hungary.) - Juhász Gyula Tanárképző Főiskola Tudományos Közleményei, Szeged, 1982. 105-113.

[4] *M. SZENTPETERI*: Villogás- és jégeső-gyakoriság évi eloszlása Magyarországon az 1968-77-es évek adatai alapján. (The annual distribution of the frequency of fulgurations and hails in Hungary on the basis of the data of the years 1968-77.) - Juhász Gyula Tanárképző Főiskola Tudományos Közleményei, Szeged, 1983. 85-94.

THE FIRST TWO YEARS OF HAIL-PREVENTION IN BACS-KISKUN COUNTY

by

Peter Peter

A Bács-Kiskun megyei jégesőelhárítás első két éve. A tanulmány a dél-baranyai kísérleti jellegű jégesőelhárító rendszer tapasztalatainak felhasználásával létesített, *1984* óta működő "Bács-Kiskun megyei Rakétás Jégesőelhárító Egység" első két évének tapasztalatairól számol be. Foglalkozik a védett terület kiválasztásának szempontjaival, a védett terület éghajlati viszonyaival, a jégesők gyakoriságával és területi eloszlásával, a Jégesőelhárító Egység felépítésével, a jégesőelhárítás módszerével és az Egységben folytatott gyakorlatával.

The study reports on the experience of the first two years of the "Bács-Kiskun County Hail-preventing Unit with Rockets", established making use of the experience of south Baranya hail-preventing system of experimental character and operating since *1984*. It deals with the aspects of the selection of the protected area's climatic conditions, the frequency and regional distribution of hails, the structure of the Hail-preventing Unit, the method of hail-supression, and its practice in the Unit.

Introduction

Hail is one of the most dangerous atmospheric phenomena. Year by year it causes considerable damage in agriculture. Agricultural production, by the transformation of its structure, and by its becoming more intensive, is growing more and more sensitive to hail.

Hail-prevention endeavours to bring about changes artificially in the internal microphysical processes of a cloud or a system of clouds, and in the microstructure of the cloud. That essentially means letting artificial ice-nucleis (silver or lead iodide) in large quantities into what is called the thundercloud's (cumulonimbus) accumulation zone (*SULAKVELIDZE*, *1965*), which is of large water concentration and where water is to be found in a supercooled state.

So the number of the ice-nucleis is increased at least a hundredfold, and by that, the water drops, which have grown supercooled, are forced to freeze away from the natural ice-nucleis. As a result of the intervention, the increase of the natural hailstones is limited; whereby many more but much smaller hailstones come into being. These, while falling, partly or entirely melt in the air-space of positive temperature before dropping onto the surface.

In Hungary it was in *1973* that a government decision was born for the introduction of the protection against hail (*WIRTH*, *1985*). Prior to that, as early as *1961*, the research team of cloud physics was formed which got, as a task, the theoretical preparation and foundation of this practical activity.

In this country the first hail-preventing unit was developed in *Baranya County*, where in *1976* the protection began.

The structure of the "Bács-Kiskun megyei Rakétás Jégesőelhárító Egység" or Bács RJE (Bács-Kiskun County Hail-preventing Unit with Rockets)

After the successful trials of intervention in *Baranya*, a decision was born for the extension of hail-prevention. The choice fell, as quasi the continuation of the *Baranya* protected area, on the southern part of *Bács-Kiskun County*, where grapes, fruits and vegetables - which are sensitive to hail - amount to an important part of agricultural produce (*Hoszszuhegy, Baja* and *Bácsalmás Agricultural Combinates*, the district of *Kalocsa*, etc.).

Subsequently to the planning and effectuation, in 1985 began the defence in the *Bács-Kiskun County Hail-preventing Unit with Rockets (Bács RJE)*.

The protected area (*PA*) of the *Bács RJE* is bordered in the west by the Danube, in the south by the *Hungarian-Jugoslav national boundary*, in the east approximately by the line *Csikéria-Kiskunhalas*, and in the north by the line *Kiskunhalas-Császártöltés-Fajsz*. Its area is approximately *5,000* km². The direction centre (*DC*) of the system settled in *Dusnok*, in the north-western tip of the protected area.

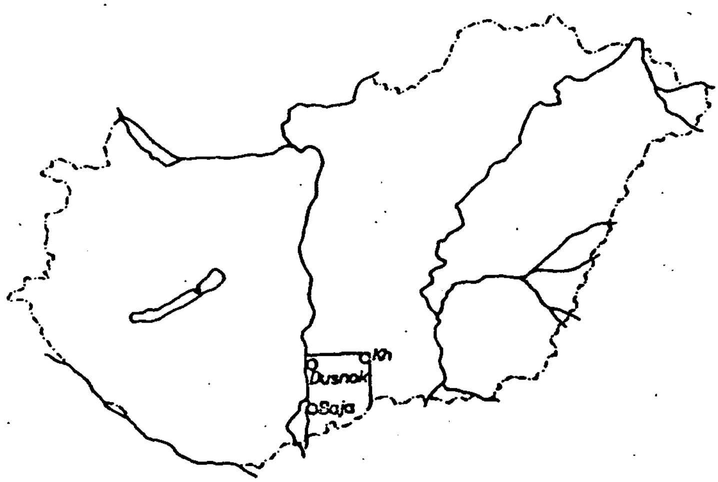


Fig. 1 Situation of the protected area of the Bács-Kiskun County Hail-preventig Unit with Rockets ("Bács-Kiskun megyei Rakétás Jégesőelhárító Egység" or Bács RJE) in Hungary

The determination of the protected area cannot be considered to be exact for several reasons:

- because of safety regulations the major settlements and their immediate environments cannot be defined;
- there are no reliable data relating to how long the nucleation makes its influence felt in the clouds, and in what way this manifests itself in the space.

Placing the direction centre into the north-western corner of the protected area carries several advantages. For example:

- the thunderstorm activity or haily processes, approaching mostly from the west, can be observed well in advance, and thus in the system, preparedness can be ordered in time;
- the area called "dead ground", which is in the immediate vicinity of the radar and has a radius of about *10* km, is confined to the smallest one possible;
- for scanning the air-space of the protected area, you have to move the aerial of the radar in sector only, which means a considerable time-saving.

In the area of the *Bács RJE*, the protection is effected from *18* rocket launching bases. Corresponding with the parameters of the method applied and of the rockets used for the intervention, these bases have been settled so that the regions with a radius of *8 km* considered to be useful should partly overlap each other (*Fig. 2*). This, in principle, makes it possible for us to send reagents over any point of the protected area.

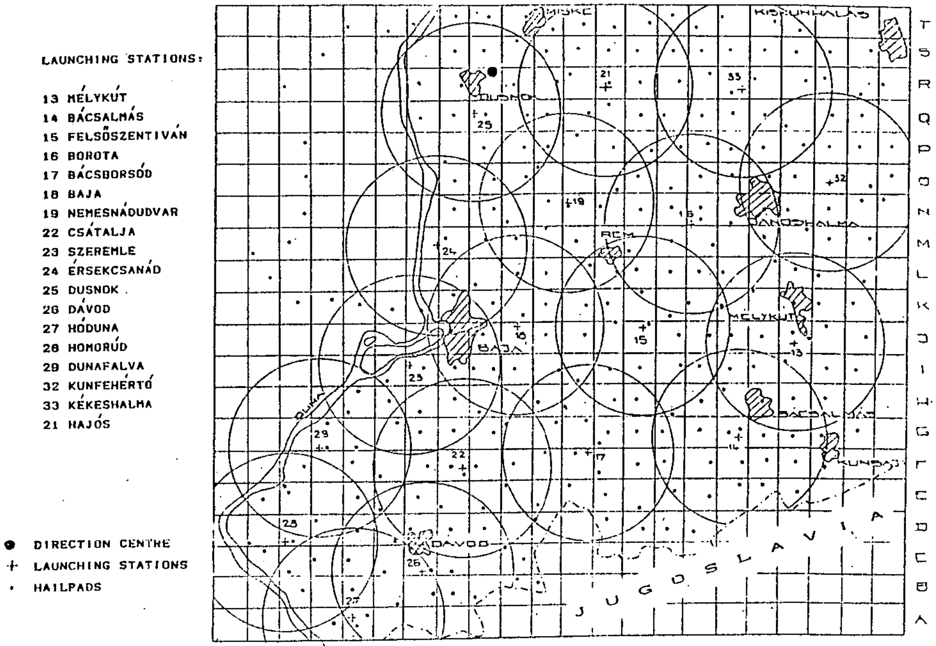


Fig 2 Protected area and networks of launching stations and hail indicators of Bács RJE

Climatic Conditions

Concerning the *Bács RJE*'s area, we only possess informations about the protection season (*1^{st} April - 31^{st} October*) and about as few as *2-3* years. For that very reason, the analysis and judgement of the data partly deviate from the usual points of view. Instead of averageings, the numbers and percentage distributions of cases have been scrutinized. In addition, the practicable aspects of hail-prevention require, too, for the protected area to be considered as a unit (abstractly punctiform).

The *Bács RJE*'s protected area belongs to this country's districts of secondary maximum thunderstorm frequency (*BACSO, 1953*). According to the obervations of many years, the number of the stormy days can be put at *20 - 30* yearly. By contrast, in *1985* in the area of the *Bács RJE* there were *37*, while in *1986* there were *54* days on which it was at at least one station of the system that thunderstorm was reported. The numbers of the thunderstorms were something greater than that; in *1985* the number was *42*, while in *1986* it was *58*. The points of time of the outbreaks of the thunderstorms, according to the ones known from literature, can mainly be dated to the afternoon hours, between *12* and *19* hours (1000-1700 GMT). In addition, the percentage of the late evening and night thunderstorms, too, is considerable, more than *20 %* (*Table 1*).

Also the distribution of hails in space and time is asystematic. Literature (*BACSO, 1953, GOTZ and MESZAROS, 1968*) keeps in mind *1-3* hails a year averagely at every measuring point in this country. On the basis of the *Bács RJE*'s measurements by hail indicators in *1984-1986*, all that is verified (*Fig. 3*). In the three years analysed, the number of the points at which *4*, possibly even *5* hails occured was inconsiderable (*Fig. 3, 1986*). From the measurements carriead out so far it seems that it is the western

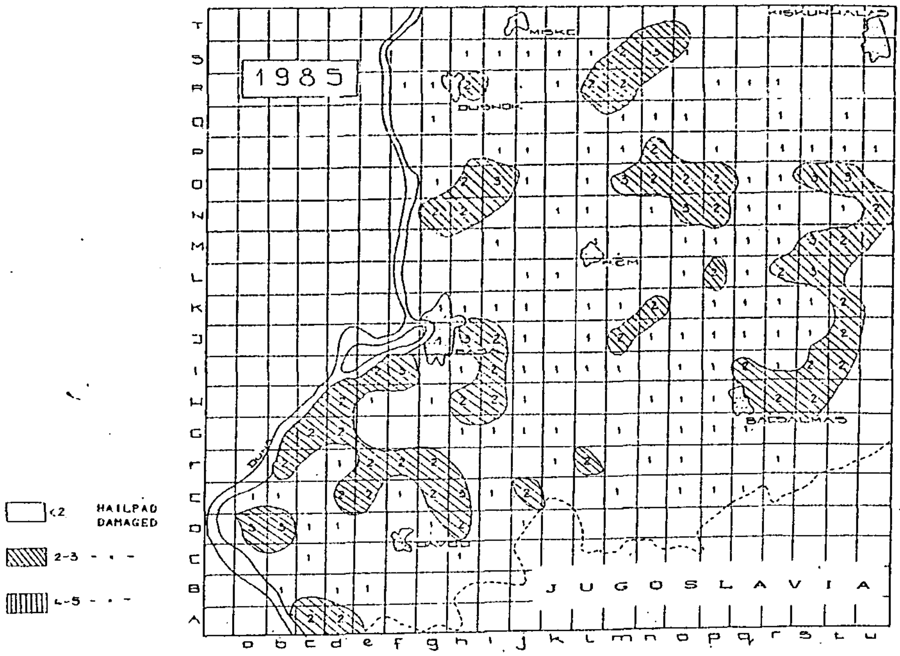


Fig. 3 Numbers of damaged hail indicators in each measuring point

edge of the protected area – first of all, the range of *Baja, Mohács and Sükösd* – as well as its south-eastern part which are most frequently reached by hailstorms. At the same time, in each of the three years id did not hail at all in a considerable part of the protected area.

The observations at the single points do not truly reflect the hail-frequency of an area. Just therefore, it is advisable to extend the investigation of hail-frequency over a major area (*1,000 km²*). According to the Hungarian researches relating to this (*GÖTZ and MESZAROS, 1968*), in this area of the Great Hungarian Plain, where also the protected area of the *Bács RJE* is to be found, it hails *6-8* times yearly. If, again, the protected area is considered as a unit, and the practicable aspects of hail-prevention are made primary, then the number of hails will be even considerably greater than that. So for instance, in *1984* there were *25*, in *1985* there were *22*, while in *1986* there were *27* days on which it hailed at at least one point of the *Bács RJE*'s protected area (*Table 2*).

Observing the monthly distribution of the hails, it turns out that most haily days occur in *May*, in *28.4 %* of the cases. This is followed by *June* and *July* (*23.0 %* and *21.6 %* respectively), then by *April* (*14.9 %*) and *August* (*8.1 %*) – (*Table 2*). Otherwise, this distribution does not differ essentially from the distribution known from literature (*BÍCSO, 1953*).

The day-time distribution of the beginnings of the hails has been calculated on the basis of the voluntary observers' reports. During three years – *1984, 1985* and *1986* – from the protected area arrived *205* reports of hail altogether (*Table 3*). In *144* cases (*70.0 %*), the hails began between *14* and *19* hours (12-17 GMT). Within that, in most cases (*17.2 %*) between *18* and *19* hours (16-17 GMT). At night and in the morning, between *22* and *13* hours, hails only occur exceptionally (*Table 4*). The day-time distribution made known considerably deviates from those known from literature.

The lengths of time of the hails, too, have been calculated from the voluntary observers' reports. Accordingly, hailing only rarely holds on for more than *5-10* minutes (*Table 5*). Of the *205* reports already mentioned, in *168* cases the duration of hailing, could also be determined; *71* times of these (*42.2 %*), the hailings did not last longer than *5* minutes; however, in as many as *77.9 %* of the cases they were of a stretch of time shorter than *15* minutes. It is noticeable that in *April, May* and *June* the hails are not only more frequent but they last longer as well.

Hail generally comes into being under specific aerosynoptic conditions, to which also contribute the physical and geographical characteristics of the area. In the evolution of these processes, the thermal stratification of the air-space, and the altitudes of the isothermal levels of *0°C*, *-5°C* and *-10°C* determining the condition of hail-formation are of decisive importance. The shaping of the thundery and haily processes as well as of the altitudes of the isothermal levels of *0°C* and *-10°C* in the first four months (*April-July*) of the defence season of the year *1985* are shown by *Fig. 4*. (There was an intervention or there were interventions on days emphasized by dotting.)

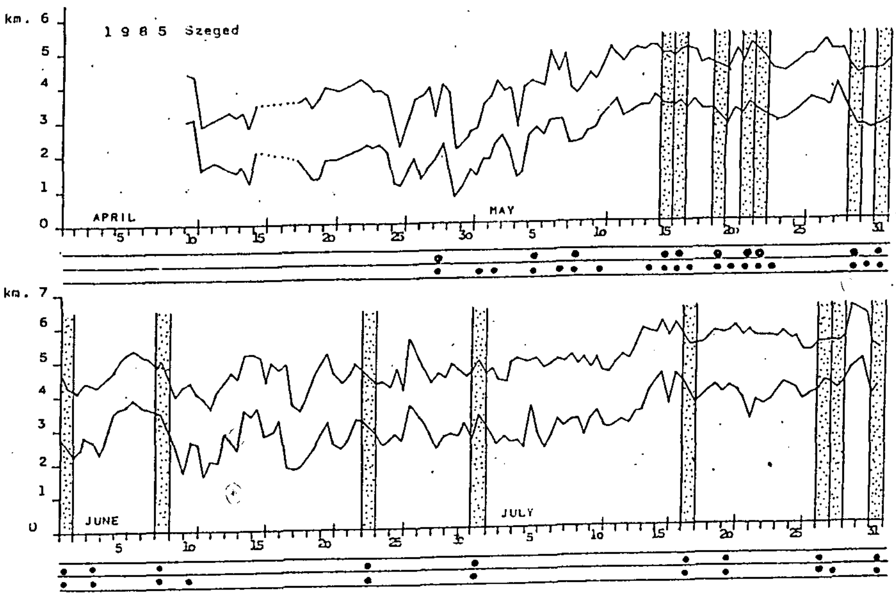


Fig. 4 Changes of the heights of the isotherms of 0°C and -10°C measured at Szeged by radio sondes (at 0000 and 1200 GMT), as well as the distributions of thunderstorms, hails and interventions between 1 April, 1985 and 31 July, 1985

It is generally accepted that the majority of hails are attached to frontal processes; in most cases they occur in a deepenining cyclone, or in the foreside of the trough. A condition of hail danger may also develop differently from that as, and more than once even in a small area. In *Fig. 5* the wether situation of 15th June 1986 and the tunderstorm and hails attaching to that can be seen. Under the influence of a weakening pressure field in the basin of the Mediterranean, there emerged though thunderstorms in Hungary all over the country; hail, however, was reported by not more than two Transdanubian stations (*Sümeg* and *Mohács*). The only meteorological station (the one in *Baja*) to be found in the protected area, also, was

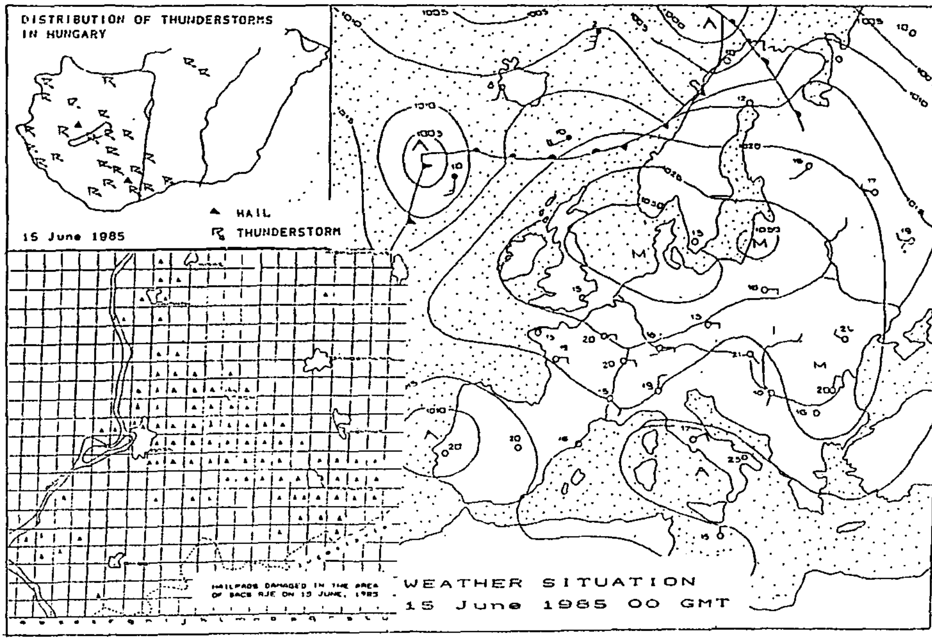


Fig. 5 Weather situation of 15 June, 1986, as well as the distribution of the thunderstorms and hails attaching to it

missed by hail. Nevertheless, almost one-third of the *Bács RJE*'s area was destroyed by hail; and in *1986* the greatest damage done by hail occurred on this day, in an area of some *7,000* hectares.

The method and practice of hail-prevention in the *Bács RJE*

Hail-prevention applies several methods and technologies in these days. In our country - and thus also in the *Bács RJE* - defence goes on by the procedure based on the principle of what is called the "competing embryo-hypothesis", and which has been worked out in the Soviet Union. To send artificial ice nuclei (silver iodide) into the clouds, rockets are used. The major parameters of both the single- and the two-stage type ALAZAN Soviet rockets are contained by *Table 6*.

As conditions of the rise and growth of hail, the following things must be realized in the cloud:

- the velocity of maximum updraught should exceed the value of $10\ ms^{-1}$,
- the maximum velocity of updraught should be in the negative temperature range,
- the temperature of the upper level of convection should be below $-25°C$,
- the moisture content of the accumulation zone should be able to ensure the moist growth of hailstones.

Under given circumstances, the water supply of the cloud is determined by the velocity of updraught.

The final size of hailstones depends on:

- the velocity of updraught,
- the thickness of the accumulation zone,
- the water supply of the accumulation zone.

The radius of hailstones is given by the relation below:

$$\bar{R}_m = \bar{R}_3^{\,3}\sqrt{\frac{N}{Nm}}$$

where $\bar{R}_3$ = the mean radius of natural hailstones,
N = the concentration of natural ice-formations,
N_m = the concentration of artificial ice-formations.

Thus consequently, if the concentration of natural ice nuclei is artificially increased a hundredfold, then the mean radius of hailstones will decrease to its one-fifth. In *Baranya County*, according to the investigations done in relation to the unidimensional cloud model (*MOLNAR, 1985*), the maximum speeds of updraught reached or exceeded *15 ms^{-1}* in all cases on the days when hails developed within the air mass. In *80 %* of the cases, the maximum speeds of updraught reached or exceeded *20 $m\ s^{-1}$*; while in *70 %* they fell between *20* and *30 ms^{-1}*. At the same time, on the 'not icy ' days they were less than *15 ms^{-1}* in one-third of the cases .

The preparation of defence begins by analysing the synoptic situation, and the thermodynamic state of the air-space. For this, thunderstorm forecasts are made twice daily. As auxiliary materials, the following things come into use: surface and contour charts, TEMP telegram (depending on the general circulation, the ascents in *Budapest*, *Szeged*, *Belgrade* or *Zagreb*), GRID + a 12 hours' forecast, as well as the unidimensional cloud model derived from the TEMP. The frequency of radar observations (whether they are made every three hours, or every hour, or continuously) is determined by the information content of the forecast (*Fig. 7*).

By the help of the cloud model, the profile of the speed of vertical updraught expectable in the thounderstorm cloud, the ice and water contents of the cloud, the temperature profile in the cloud, as well as the growth of the hailstones during their rise can be determined. It is in this manner that the range of the thunderstorm cloud between *−5°* and *−10°C*, which must be nucleated during the intervention can be marked out (*Fig. 6*).

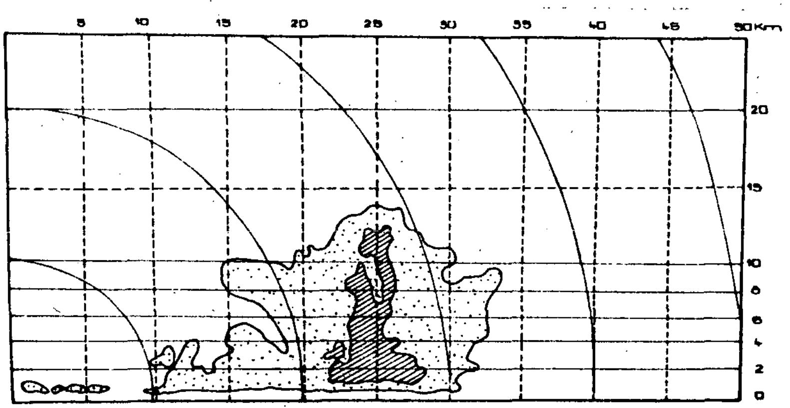


Fig. 6 The (shaded) area to be nucleated of the hail-dangerous thunderstorm cell

As the first step of the intervention (nucleation) procedure, the detection of the air-space is carried out by a Soviet made MRL-5 meteorological radar, deposited in the direction centre, and operating at wave-lengths of *3.2 cm* and *10 cm*. When the intensity of the reflected sign exceeds the threshold of sensitivity of the radio locator, then the radio echo of the sounded object appears, in the form of a bright spot, on the screen of the of the radar. (This is called the reflection zone of the meteorological target.) The intensity of the signal released by the locator and reflected off a cloud, depends on the sizes, physical conditions and shapes of the cloud particals. It is the sizes of a precipitation particle that are the most important factor, for the intensities of the reflections are proportional to the sixth power of the diameters of the particles. This means that if the diameter of the cloud particles increase by an order, then the reflected signals will be a million times intenser.

When the parameters got from the radio locator measurings reach the criterions of the danger of icing determined in the method, the nucleation of the cloud starts (*Fig. 7*).

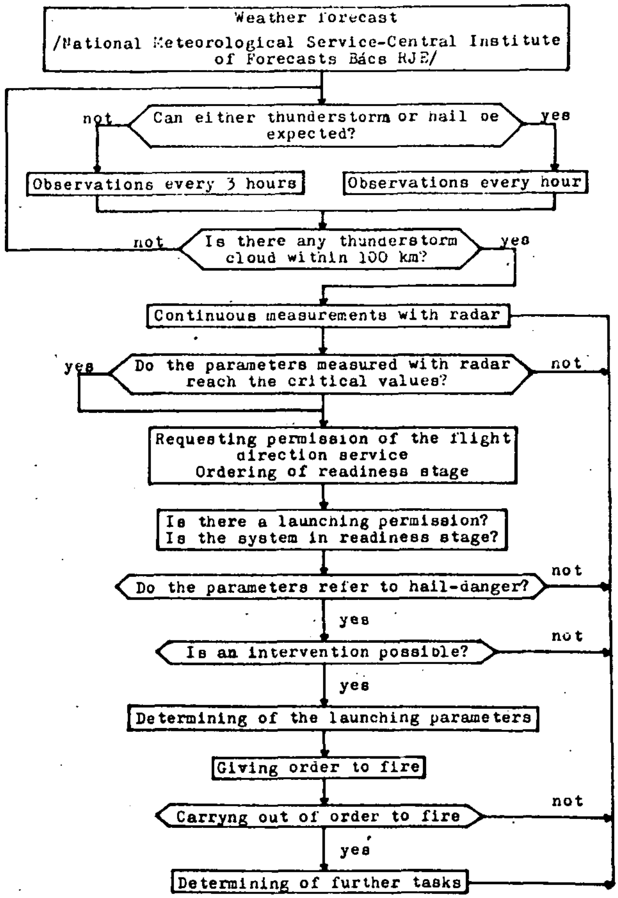


Fig. 7 Process-figure of the intervention procedure

If the nucleation starts too early, there exists a danger that we intervene needlessly, already before the cloud becomes hail-dangerous. If, again, the intervention is late, and the development of hail has already taken place in the cloud; the intervention will be ineffective.

For nucleating the hail-dangerous cells, the direction centre gives, at *V.H.F.*, the rocket launching base most suitable for the intervention an order to fire. The trajectories of the rockets launched in the directions of a triple fan are so determined by the leader of the intervention that the greatest part of the courses of the rockets should fall between the isothermal levels of *-5°C* and *-10°C*, there where hailstone formation is the most intensive. During the reagent dispersion lasting about *35* seconds, *60-120* grams of reagents get into every cubic kilometre of the cloud; ensuring with this the more than a hundredfold ice nucleus concentration postulated by the principle of competition.

In the *1985* season of defence, continuous observations were on *28* days, in the *1986* one on *35*. The number of the days with intervention was considerably smaller, *14* in *1985*, while it was *24* in *1986*. In the two seasons, measurings with radio locators were carried out relating to *1,271* cells altogether. Of these, *166* were nucleated (*Table 7*).

The cells measured have been put among three groups:

- *icy* ones - the ones to that some unambiguous information of ice could be added;
- *not icy* ones - the ones to that no information of ice could be added;
- *uncertain* ones - the ones that had either been measured outside the defended area, and their qualities are not decidable; or had been in the defended area though, but from the available informations of ice it cannot be unambiguously decided from which cells they derive

The ratio of the icy cells to the nucleated ones was *73:57* in *1985*, while it was *80:109* in *1986*. If, in turn, we also consider that it also hailed from at least a part of the cells put into the group of the uncertain ones, then the conclusion can be reached that a considerable part of the hail-dangerous cells received no intervention.

The observation of the regional distribution of the hails

The intensities of hails, their distribution in space and time, as well as the cloud-modificating effect of nucleation can only be valued by an observation network adequate for this. For that, the usual meteorological network is not suitable, is too sparse.

From the *Bács RJE*'s protected area and its immediate vicinity, a multi-channel information system is available.

They are as follows:
- the verbal reports of the rocket launching bases,
- the hail reports of the voluntary observers,
- the network of hailpads,
- the reports about the damage done by hails,
- the measurings with radio locators.

With most information of these supply the written hail reports of the voluntary observers. We come to know from them the place, beginning and duration of a hail, the distribution of the hailstones according to size, the damage caused, etc. (*Tables 3, 4, 5, and 8*). The numbers of hail reports sent in of a hail-day alternated between *1* and *49*; the ones of those sent in from the protected area, between *1* and *36*.

For estimating the areas of thunderstorm cell size, it is the network of hailpads which is suitable. To this end, the protected area of the *Bács RJE* is divided into quadrate areas of *3 km × 3 km* (*Fig. 2*). At some known point of every area of *9* km^2 like this a hailpad is placed.

The hailpads are slabs with a volume of *30 cm × 30 cm × 2 cm*, made from polyurethane foam, on which an aluminium foil of a thickness of $10\,\mu m$ is sticked. Having been laid on metal plates, the polyurethane slabs are fixed horizontally on a stand. On these deformable plates even hailstones with a diameter smaller than *5 mm* leave their marks. Hailmarks left on a surface of *900 cm²* like that can be counted. We can determine the according-to-size distribution of the hailstones, then from that we can calculate their total mass and kinetic energy (*SZEKELY and ZOLTAN, 1984*). If we project the data, obtained so, to the damaged area, then we can estimate the degree of the loss of vegetable culture.

In the *Bács RJE*, for determining the real sizes of hailstones we use certified measuring slabs. They are so made that from a definite height, steel balls of a known density but of different diameters are dropped onto a usual hailpad slab. Comparing the impressions, which have come into being so, with the hailstone marks, the diameter of a hailstone can straight be visually determined. The advantage of the procedure, first of all, consists in the fact that it is easy to manage, and is operative.

Setting the hailpads out into the place pointed out in advance (for the most part into the same point) is performed in spring, before the beginning of the season of defence. Their gathering in when finishing the season. In summer, in times of hailing the hailpads are counterchecked (the damaged ones are replaced) according to a programme fixed in advance, or in all cases when a hail-dangerous thunderstorm cell has passed over the area in question. In this way, it is always up-to-date informations that are available in the network of hailpads.

In the defended and neighbouring areas of the *Bács RJE*, the observations were executed in *1984* by *253*, in *1985* by *265* and in *1986* by *304* hailpads.

Table 8 contains the according to size distribution of the hailstones. The first half of the table has been made by processing the hail reports of the voluntary observers. The reports classify the fallen hailstones according to their sizes. Occasionally there may also occur hailstone sizes classable among all the size categories. The second half of the table contains the measurements with the hailpads; within that the monthly or yearly numbers of the damaged hailpads, and the diameter of the biggest hailstone measured in a month or a year.

Damage done by hail. Compensation

In *Bács-Kiskun County*, before the introduction of hail-prevention, averagely *25,971* hectares of the insured areas had been befallen by hails yearly, and the sum of the compensations amounted to *Ft 98,418,000* on a yearly average. This means that to each damaged hectare fell *Ft 3,790*. Of late years, the extent of the areas insured against damage done by hails has increased because the conclusion of the insurance contract is compulsory for the co-operative and state farms in the protected area.

In *1984*, reparable damage, i.e. damage over *5 %* arose on *56,689* hectares in the protected area. The areas which had suffered damage over *5 %* came to *15,725* hectares in *1985*, while in *1986* they came to *17,811* hectares (*Table 9*). In fact, the extent of the areas which had suffered damage by hails must have been essentially larger than that; namely these numbers do not include the areas not insured and the ones which had suffered less damage than *5 %*, as well as the damage which had arisen in small farms. To this we should only like to mention that in *1985* and *1986* the extent of the areas which had suffered less than *5 %* (consequently not reparable) damage was almost just as large as that of the ones which had suffered greater than *5 %* damage.

In *1985* the *Allami Biztosító* (the Hungarian State Insurance Company) paid damages of *106.9 million* forints for the damage done by hails. In *1986* the sum of the indemnities touched *123.9 million* forints.

In the majority of cases, a considerable part of the damage done by hail arises on a few, more than once *on 1-2 days*. So for example, in the later protected area, on one single day, *2 July 1984* reparable damage done by hail arose, totalling *30,018* hectares. That amounts to *54.3 %* of the area which in 1984 suffered reparable damage by hail, and which is almost as great in itself as the areas that suffered reparable damage in the years 1985 and 1986 taken all together. Similarly, on *8* and *23 June 1985*, too, 14,973 hectares were overtaken by reparable damage by hail, what correspond to *51.1 %* of the total damaged area of that year.

Conclusions

In the - short - period analysed, the spatial and temporal distributions of the stormy and haily processes, in many respects agreed, with those known from literature, but, on numerous points, departed from them. It was relatively often that hail occurred in the evening and night hours. The hail prevention system presented conforms to the random distribution of atmospheric phenomena, in the course of its operation, however, the limits of traditional, punctiform observations show themselves.

Although in the area of the *Bács RJE*, between 1984 and 1986, hail fell on *22-27* days annually, nearly half of the damage, which occurred, was each year concentrated on one or two days.

Table I

Points of time of the beginnings of thunderstorms risen in the area of the *Bács RJE* (1985-1986)

Year	Months	Number of days with thunder-storm	Number of thunder-storms altogether	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
	IV	1	1														1										
1	V	18	20	1			1							1	1	3	2	3		4				1	2	1	
9	VI	5	6			1										1	1	1				1				1	
8	VII	5	6	1														2			1				1		1
5	VIII	6	7				1								1		2	1	2								
	IX	2	2																			2					
Sum total		37	42	2	-	1	2	-	-	-	-	-	-	1	2	4	6	7	2	4	1	3	-	1	3	2	1
1	IV	6	6	1									1				1	1			1					1	
9	V	10	10		1								1			2	2		1			2		1			
8	VI	17	21					1		1		1		1		3	3		2	4		2			1	2	
6	VII	12	12		1				1				1				2	2	2	1	1					1	
	VIII	9	9		1								1				1				2	2			1	1	
Sum Total		54	58	1	3	-	-	1	1	1	-	1	4	1	-	5	9	3	5	5	4	6	-	1	2	5	-
1985-1986 Sum total		91	100	3	3	1	2	1	1	1	-	1	4	2	2	9	16	10	7	9	5	9	-	2	5	7	1

Table 2

Distribution of hail-days in the area of the *Bács RJE* (1984-1986)

Year	Apr.	May.	June	July	Aug.	Sept.	Oct.	Sum total
1984	5	7	5	5	2	1	-	25
1985	1	9	4	5	1	1	1	22
1986	5	5	8	6	3	-	-	27
1984-1986	11	21	17	16	6	2	1	74
1984-1986 %	14.9	28.4	23.0	21.6	8.1	2.7	1.3	100.0

Table 3

Distribution of hail reportd received from the network of voluntary observers of the *Bács RJE* (1984-1986)

			Apr.	May	June	July	Aug.	Sept.	Oct.	Total
1984	About how many days have they reported	total	7	12	6	5	4	1	-	35
		from PA	5	6	1	4	2	-	-	18
	Number of reports	total	14	67	45	45	18	6	-	195
		from PA	6	20	17	17	3	-	-	63
1985	About how many days have they reported	total	2	11	3	5	4	2	1	28
		from PA	-	6	3	4	1	1	1	16
	Number of reports	total	3	124	33	37	6	8	1	212
		from PA	-	26	13	9	1	1	1	51
1986	About how many days have they reported	total	6	6	10	2	3	-	-	27
		from PA	4	3	6	2	2	-	-	17
	Number of reports	total	93	53	53	21	13	-	-	233
		from PA	40	19	23	5	4	-	-	205
1984-1986	About how many days have they reported	total	15	29	19	12	11	3	1	90
		from PA	9	15	10	10	5	1	1	51
	Number of reports	total	110	244	131	103	37	14	1	640
		from PA	46	65	53	31	8	1	1	205

PA = Protected Area

Table 4

Day-time distribution of the beginnings of hails fallen in the area of the *Bács RJE*.
(On the basis of the voluntary observers' reports, 1984-1986.)

Hours

Year	Months	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	0-24
1	IV					1							1				1	3								6
9	V										1					11		3	5							20
8	VI														3	4	2	1	1	5	1					17
4	VII															1		5	11							17
	VIII																					1	1	1		3
	Total					1					1		1		3	16	3	12	17	5	1	1	1	1		63
	V													1	2	2	4	12	1		2	1		1		26
1	VI															3	8	1		1						13
9	VII																3			3	2	1				9
8	VIII														1											1
5	IX																			1						1
	X														1											1
	Total													1	4	5	15	13	1	5	4	2		1		51
1	IV											1	1	1			3	3		20	3	4	4			40
9	V														3	6	6	1			2			1		19
8	VI					1		1	2										1	4			13		1	23
6	VII																1	1	3							5
	VIII																1			2					1	4
	Total					1		1	2			1	1	1	3	6	11	5	4	26	5	4	17	1	2	91
1984-1986	Sum total					2		1	2		1	1	2	2	10	27	29	30	22	36	10	7	18	3	2	205
1984-1986	%					1.0		0.5	1.0		0.5	0.5	1.0	1.0	4.9	13.2	14.1	14.5	10.7	17.5	4.9	3.4	8.8	1.5	1.0	100.0

Table 5

Distribution according to duration of hails observed in the area of *Bács RJE*.
(On the basis of the voluntary observers' reports, 1984-1986.)

Length of time (minute)

Month	Year	1- 5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-75	76-90	Hail-reports total
A	1984	3	-	-	-	-	-	-	-	-	-	-	1	-	1	5
p	1985	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
r	1986	20	5	4	-	-	3	-	1	-	-	-	2	-	-	33
	Total	23	5	4	-	-	3	-	1	-	-	-	3	-	1	40
M	1984	7	4	-	3	-	1	-	-	-	-	-	1	1	-	17
a	1985	5	5	3	2	1	2	1	-	-	-	-	-	-	-	19
y	1986	7	3	2	1	1	-	-	-	-	-	-	-	-	-	14
	Total	19	12	5	6	2	3	1	-	-	-	-	1	1	-	50
J	1984	5	3	3	1	-	1	-	-	-	-	-	1	-	-	14
u	1985	3	5	4	-	-	-	-	-	-	-	-	-	-	-	12
n	1986	5	4	4	4	-	-	1	1	-	-	-	-	-	-	19
	Total	13	12	11	5	-	1	1	1	-	-	-	1	-	-	45
J	1984	4	5	3	2	-	1	-	-	-	-	-	-	-	-	15
u	1985	4	2	-	-	-	-	-	-	-	-	-	-	-	-	6
l	1986	3	-	-	1	-	1	-	-	-	-	-	-	-	-	5
	Total	11	7	3	3	-	2	-	-	-	-	-	-	-	-	26
A	1984	2	-	-	-	-	-	-	-	-	-	-	-	-	-	2
u	1985	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
g	1986	2	-	-	-	-	-	-	-	-	-	-	-	-	-	2
	Total	5	-	-	-	-	-	-	-	-	-	-	-	-	-	5
S	1984	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
e	1985	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
p	1986	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
t																
	Total	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
O	1984	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
c	1985	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
t	1986	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
1984-1986 Apr - Oct Sum total		71	37	23	14	2	10	2	2	-	-	-	5	1	1	168
%		42.2	22.0	13.7	8.3	1.2	6.0	1.2	1.2	-	-	-	3.0	0.6	0.6	100.0

Table 6

A few characteristic data of the Soviet rockets of ALAZAN type used by the *Bács RJE*

Characteristics	Type of rocket Alazan M	Alazan M-1SzT	Alazan 2M	Alazan 2M-1SzT
Diameter (mm)	82.5	82.5	82.5	82.5
Length (mm)	1296-1312	838-850	1343-1356	884-895
Mass (kg)	9.64	6.54	8.30	6.80
Mass of reagent charge, PbJ_2(kg)	1.12	1.12	1.28	1.28
Maximum flying height, (km)	7.9	4.3	9.08	4.3
Maximum flying range, (km)	9.7	5.1	10.0	4.6
Time of self destroying, (s)	43+4	43+4	47	47
Duration of dispersing, (s)		about 35		
Output of ice nuclei, (number of pieces)	2.10^{12} - 5.10^{12}			

Table 7

Number of thunderstorm cells measured by a radio locator and nucleated in 1985-1986

Year	Month	Cells measured by a radar Total	Icy	Non-icy	Dubious	Nucleated	Number of days with intervention	Height of cloud top, km
	Apr.	7	-	5	2	-	-	5.4
1	May	290	52	165	73	42	7	14.0
9	June	107	11	90	6	5	3	13.2
8	July	66	10	44	12	10	4	17.8
5	Aug.	26	-	22	4	-	-	10.0
	Total	496	73	326	97	57	14	17.8
	%	100.0	14.7	65.7	19.6	11.5	X	X
	Apr.	107	22	12	73	14	3	12.2
1	May	207	24	54	129	29	5	12.8
9	June	263	14	40	209	29	6	15.4
8	July	96	15	14	67	26	6	15.0
6	Aug.	102	5	23	74	11	4	12.8
	Total	775	80	143	552	109	24	25.4
	%	100.0	10.3	18.5	71.2	14.1	X	X
1985-1986	total	1271	153	469	649	166	38	17.8
1985-1986	%	100.0	12.0	36.9	51.1	13.1	X	X

Table 8

Year	Month	Number of reports	Report of voluntary observers: Distribution of hailstones according to size (case-number, mm)								Report of voluntary observers: Diameter of the biggest hailstone	Measuring by indicators: Number of damaged indicators	Measuring by indicators: Diameter of the biggest hailstone
			0-5	5.1-7.5	7.6-10	10.1-12.5	12.6-15	15.1-20	20.1-25	25<	(mm)	(piece)	(mm)
	IV	6	4	-	-	2	-	-	-	-	12.5	21	15.0
1	V	20	10	11	9	6	1	2	-	-	20.0	151	22.5
9	VI	17	9	11	6	3	1	-	-	-	15.0	133	20.0
8	VII	17	4	4	2	4	6	9	11	9	25.0	53	45.0
4	VIII	3	1	1	1	-	-	1	1	-	25.0	40	25.0
	IX	-	-	-	-	-	-	-	-		-	11	15.0
	Total	63	28	27	18	15	8	12	12	9	25.0	409	45.0
	IV	-	-	-	-	-	-	-	-	-	-	7	7.5
1	V	26	15	17	10	2	1	-	-	-	10.0	124	20.0
9	VI	13	5	8	6	5	-	-	-	-	12.5	68	22.5
8	VII	9	6	2	1	1	1	2	1	-	25.0	18	17.5
5	VIII	1	1	-	-	-	-	-	-	-	5.0	-	-
	IX	1	1	-	-	-	-	-	-	-	5.0	-	-
	X	1	1	1	-	-	-	-	-	-	7.5	-	-
	Total	51	29	28	17	8	2	2	1	-	25.0	217	22.5
	IV	40	15	16	17	8	4	2	-	-	20.0	98	22.5
1	V	19	8	7	9	8	-	-	-	-	12.5	65	22.5
9	VI	23	11	13	6	3	4	1	-	-	20.0	123	22.5
8	VII	5	-	-	3	3	1	-	-	-	15.0	35	22.5
6	VIII	4	-	2	2	2	3	2	2	-	25.0	27	20.0
	Total	91	34	38	37	18	12	5	2	-	25.0	348	22.5
1984-1986	Sum total	205	91	93	72	41	22	19	15	9	25.0	974	45.0

References

BACSO, N. - KAKAS, J. - TAKACS, L., 1953: Magyarország éghajlata. (The climate of Hungary) - OMI Hivatalos Kiadványai, VII. kötet. (Official publications of the National Meteorological Institute of Hungary, Volume XVII.) 206-208.

GÖTZ, G. - MESZAROS, E., 1968: A jégesők gyakoriságának területi eloszlása a nyári félévben Magyarországon. (The areal distribution of the frequency of hails in the summer half-year in Hungary) - Időjárás, *72.*, 1. 46-54.

MOLNAR, K. - CSABAI, D. - SHTOIANOV, ST., 1984: Jégesők előrejelezhetősége zivatarfelhő-modell segítségével. (Possibility of hail forecast with help of the thunderstorm model) - Időjárás, *88.*, 1. 46-51.

SZEKELY, CS. - ZOLTAN, CS., 1984: A jégesőindikátor és felhasználásának lehetőségei. (The hail-indicator and possibility of its utilization) - Időjárás, *88.*, 1. 32-45.

WIRTH, E. - MARKO, T. - SÖVER, F., 1984: A jégesőelhárítás értékelése: fizikai hatások és gazdasági következmények. (The valuation of hail-prevention : physical effects and their economic results) - Időjárás, *88.*, 1. 3-20.

WIRTH, E., 1985: Jégesőelhárítás Magyarországon. (Hail-prevention in Hungary) - Időjárás, *88.* 2. 57-85.

WIRTH, E. - ZAKOCS, J. - FÖLDVARI, J., 1985: Jégesők, jégkárok, védekezés, biztosítás. (Hails, damage done by hails, protection, insurance) - Mezőgazdasági Kiadó, Budapest

DECISION STRATEGIES BASED ON FORECASTS OF ALTERNATIVE WEATHER STATES

by

J. Mika

CENTRAL INSTITUTE OF ATMOSPHERIC PHYSICS, BUDAPEST, HUNGARY

Alternatív időjárási állapotok előrejelzésén alapuló döntési stratégiák. Két egymást kizáró időjárási állapot egyikének bekövetkezésére vonatkozó éghajlati valószínűségek, kategórikus prognózisok illetve valószínűségi előrejelzések optimális felhasználását mutatjuk be egy általános döntési helyzetben, mely két adekvát és egy kompromisszumos intézkedés közül enged választást a prognózis tartalmától és az elemi gazdasági következményektől függően. Mindhárom időjárási információ-típusra megadjuk az optimális stratégia kiválasztásának paraméteres kritériumait. E kiválasztás az éghajlati információt felhasználó három triviális stratégia esetén három, a kategórikus prognózis kilenc lehetséges stratégiájára pedig mindössze hat egyenlőtlenség megoldását igényli. A valószínűségi prognózis esetében kimutathatjuk, hogy a kompromisszumos intézkedés felhasználása nem minden gazdasági paraméter-együttesre ad jobb stratégiát, mint a két adekvát intézkedés közötti határ-valószínűséget optimálisan kiválasztó stratégia. A paraméteres stratégia-kijelöléseket a *Péczely*-típusokhoz kapcsolódó meteorológiai példával is szemléltetjük.

Optimal application of climatic probabilities, categorical and probabilitic forecasts of two alternative weather states is demonstrated in a generalized decision situation allowing the choice between two adequate and one compromizing operations in connection with the content of the forecast and the elementary financial consequences. Criteria for choosing the optimum strategy expressed by parameters of the decision model are presented for the three types od weather information. This choice demands the solution of three inequations in case of the three possible strategies based on climatic information and only six inequations for the nine strategies applying categorical forecasts. In case of probabilistic forecasts it is demonstrated that the application of a compromizing operation improves the best strategy with the two adequate operations not for all possible ensembles of the economical parameters. Parametrized strategy specifications are illustrated in a meteorological example connected with macrosynoptic types defined by *Péczely*.

1. Introduction

Weather forecasts are generally applied in economical decisions mainly based on subjective reflections of the likely gains or losses in connection with the possible operations, the external conditions (eg. weather in our case), the a priori probabilities of the conditions, the elementary financial consequences of each operation influenced by the actual external condition, the decision criterion and strategies to fulfill this criterion (*ANDERSON et al.*, *1977*). The appearance of subjectivity in the decision is generally caused by the complexity of real decisions and the limited accuracy in estimations of the elementary consequences. Nevertheless there are some simple operative decisions where the main uncertainty is the weather condition and quantitative decision models are applied.

The uncertainty of future weather conditions can be decreased to some extent studying the a priori probability of the weather conditions, i.e. the climate of the area in question, which in practice can be approximated by the statistic of weather elements from the past. (The detected and projected climate variations can generally be neglected in case of activities influenced by daily weather conditions but they are worth taking into consideration if the process is governed by longer time averages eg. monthly means – *MIKA and BONCZ, 1983*, *KOPPANY, 1987* – .)

A generally more efficient estimation for the expected weather condition is the use of a continous stream of specialized forecasts (i.e. processed and designed just for this decision) that can also integrate the information on the initial conditions of the atmosphere. However there is a limitation also int. he second alternative namely the uncertainty of the forecast-skill which is mainly caused by the effort of forecasting centers to assimilate the maximum of the attainable information and the experience of the experts that a combination of objective methods with the subjective (synoptical) experience gives better forecasts than any objective routine alone. Disadvantages of this attitude are the possible trends and fluctuations in the amount of the utilized information before releasing the forecasts and the appearance of subjectivity in the forecasts. These circumstances make the forecast-skill nonstationary in time. This uncertainty of the actual forecast can not be resolved by specification of a generalized numerical character reflecting the proportion of succesful forecasts (e.g. in percents) because it does not determine the necessary input parameters of the decision-model unequivocally. The decision-maker therefore needs the two-dimensional probability distribution of the forecast-reality ensamble which in case of discrete elements can be expressed in the form of a contingency table (*KOPPANY, 1975*).

In this connection some methods not applying the complete set of attainable information but achieving a reasonable and strictly stationary skill can also be useful in several simple decision problems. (Nonstationarity connected with the diurnal or annual cycles can usually be satisfactorily excluded by grouping the same phases into separate samples.)

A possible way to this kind of forecasts can be the combination of the conditional probability distribution in different macrosynoptic types with the numerical forecast of pressure field applying a recognition method of macrotypes. For Hungary the macrosynoptic classification derived by *Péczely* seems to be the most promising for this purpose because of its little areal coverage [see *PECZELY (1957,1961,1983)* or *KAROSSY (1987)* for further investigations with the typization].

In *Section 4* we show an example for assimilation of forecasts based on these macrotypes: the case of three operations and two alternative weather states. The formulae for finding the optimum strategy in case of categorical and also of probabilistic forecasts - being the main results of this study - are derived in *Section 3*, while the decision problem and the case of climatic information (ie. absence of the specialized forecasts) are designed in *Section 2*.

2. The decision problem and use of climatic information

Let us assume that our economical activity is determined by two conditions of weather X_1 and X_2 (eg. the existence or lack of precipitation, the exceeding of a threshold value in a continous weather element like temperature or wind speed, etc.). Both possible conditions involve the ad equate operations O_1 and O_2 (eg. preventive measures or doing nothing), but there is a thiird operation O_c (eg. making some protection possible if X_1 takes place) as a result of a compromise between the two possible conditions. The a priori (climatical) probability of condition X_1 is P while the probability of condition X_2 is $(1 - P)$.

We also have consequences of each operations which are functions of the weather condition realized as presented in *Table Ia*. Now and in the following we calculate the mean loss (or loss comparing to some idealistic gain) assuming that the decision criterion is the minimization of the loss in a long time average.

A lower estimation ofthe mean loss is

$$L_{min} = AP + B(1 - P) \qquad /1/$$

which by all means appears independently of the forecast-skill or the decision strategies. As our aim is to determine the optimum strategy we can leave out $L_{\ast 1 \ast}$ in each term of our calculations (*Table Ib*). A further reducing of our calculations is possible inthe following way: We can assume without any limitation of generality that

$$d > a \qquad /2/$$

in the loss-matrix, because it only makes the usage of indices unambigous. On the other hand the essence of the compromizing operation is that

$$b < d \qquad /3/$$

and

$$c < a, \qquad /4/$$

therefore we can operate with a transformed loss-matrix (*Table Ic*), where

$$a' = \frac{a}{d} \qquad /5/$$

$$b' = \frac{b}{d} \qquad /6/$$

$$c' = \frac{c}{d}\,. \qquad /7/$$

Table I

Reduction of the loss-matrix from its complete version expressed in absolute units (*Ia*) to the net losses in relative units (*Ic*) through the net version in absolute units (*Ib*).

Ia

	O_1	O_c	O_2
X_1	A	A+b	A+d
X_2	B+a	B+c	B

Ib

	O_1	O_c	O_2
X_1	0	b	d
X_2	a	c	0

Ic

	O_1	O_c	O_2
X_1	0	b'	1
X_2	a'	c'	0

In *Table Ic* $0 < a' > 1$, $0 < b' < 1$ and $0 < c' < 1$. In order to simplify our calculations we omit the ( )' indications in the following but it is worth mentioning that everywhwere the last version of the loss-matrix (*Table Ic*) is bearing in mind.

Having only the a priori (climatical) information on the weather condition the decision-maker has to choose one operation which is the most promising according to his decision criterion (ie. the minimization of the average loss in our case). For the three possible strategies (operations) the average losses are

$$L(O_1) = (1 - P)a \qquad /8/$$

$$L(O_c) = Pb + (1 - P)c \qquad /9/$$

$$L(O_2) = P \qquad /10/$$

To choose the best strategy from the three possible ones we have to solve three inequalities presented in *Table II* together with the specification of the optimum strategy in case of possible logical values of the inequalities (ie. true or false). Although these inequalities are not independent of each other, none of them can be omitted if all possible values of the P, a, b and c parameters can be realized. On the other hand in the case of a given set of parameters two inequalities are enough for finding the best strategy but we can not establish a priori which the redundant one is.

Table II

The key inequalities and decision rules in case of apriori (climatical) information. In case of (+) the in-equality should be true and in case of (-) false in order to make the marked operation being the optimum. Mark (0) means that the value of the inequality is indifferent. (Parameters a, b and c are defined in *Table Ic* but the accent marks are omitted.)

	Inequalities	O_1	O_c	O_2
I.	$\frac{a-c}{b} < \frac{P}{1-P}$	+	+	0
II.	$a < \frac{P}{1-P}$	-	0	+
III.	$\frac{c}{1-b} < \frac{P}{1-P}$	0	-	-

3. The decision problem with special weather forecasts

Two different weather forecast syntaxes are possible. The first one contains a categorical statement about the weather in future (X_1^* or X_2^*) while the second possibility is to give the π_1 probability of condition X_1 (or $\pi_2 = 1 - \pi_1$ for X_2). The more sophisticated version is the second one but its economical potential can be effectively realized only if the economical parameters are well-known and the forecast is undistorted ie. the notified probability is really equal to the true one. In order to assure this criterion in the following we also assume that both forecasting syntaxes are results of purely objective methods. In addition to it we also neglect the costs of getting the forecasts.

Calculations presented below are not new in mathematics of economical decisions but likely in literature on application of meteorological forecasts in decisions. For example in the monography by ZHUKOVSKY (1981) containing several decision problems with quite numerous references from different countries there is not a complete solution of the problem neither for categorical nor for probabilistic forecasts in case of the situation with two adequate and one compromizing operations. The only issue (BELENKY et al., 1974) for the categorical case of our *Section 3.1* with two strict limitations of generality. The first one is that the percentage of good forecasts is the same for both alternative weather states and the second one is that the probability of each state is equal to the frequency of its forecasting. At the same time in the case of probabilistic forecasts the optimity of the strategy-type containing three operations is assumed to be optimal a priori which can be not the case as it is demonstrated in *Section 3.2*.

3.1 Categorical forecasts

The skill of weather forecasting in case of categorical syntax (stating X_1^* or X_2^*) can be designed as a contingency matrix presented in *Table II*. The elements of this matrix are formed as products of the a priori probabilities and the conditional probabilities [($p_1 = P(X_1^* | X_1)$ and $p_2 = P(X_2^* | X_2)$] of succesful forecasts presuming that the given weather condition takes place. The sum of the four matrix-elements is equal to *1*.

Having 3 possible operations and receiving a two-category forecast the decision-maker can choose from nine possible strategies including the three a priori strategies (ie. neglecting the forecasts) presented in *Section 2*. The nine strategies are demonstrated in *Table IV* together with the average losses derived by appropriate production of matrices presented in *Tables III* and *Ic*.

Table III

The matrix of forecast-skill for categorical forecasts: $p_1 = P(X_1^* | X_1)$, $p_2 = P(X_2^* | X_2)$

	X_1^*	X_2^*
X_1	$p_1 P$	$(1-p_1)P$
X_2	$(1-p_2)(1-P)$	$p_2(1-P)$

Table IV

The possible 9 strategies and their average losses in case of categorical forecasts

Strategies	X_1^*	X_2^*	Average losses
1.	O_1	O_1	$(1-P)a$
2.	O_1	O_2	$(1-p_2)(1-P)a + (1-p_1)P$
3.	O_1	O_c	$(1-p_2)(1-P)a + (1-p_1)Pb + p_2(1-P)c$
4.	O_c	O_2	$Pb + (1-p_2)(1-P)c + (1-p_1)P$
5.	O_c	O_c	$Pb + (1-P)c$
6.	O_c	O_1	$p_2(1-P)a + p_1 Pb + (1-p_2)(1-P)c$
7.	O_2	O_c	$(1-p_1)Pb + p_2(1-P)c + p_1 P$
8.	O_2	O_1	$p_2(1-P)a + p_1 P$
9.	O_2	O_2	P

The strategy-seeking algorithm means the solution of inequalities expressing the relations between the average losses. In order to find a general solution first we formed these inequations for a pair by pair comparison of the nine strategies. The number of these inequations is *36* but there are *6* relations repeated three times which determine the optimum strategies without the other *18 relations. These 6* inequations and the key to the choice of the best strategy are demonstrated in *Table V*. This table is a generalization of *Table II* from the a priori case. For the general solution in case of the whole set of parameters all the *6* inequations are needed while in case of a given set of parameters four ineauations (not being determined in advance) are enough.

The benefit in average losses applying the optimum strategy as compared to any other one can be determined by subtracting the average losses presented in *Table IV*. Besides this absolute benefit the gain relative to the a priori one can also be analyzed (*NIKA, 1982*), but instead of further discussions concerning to these gains we turn to decision strategies in case of probabilistic forecasts.

Table V

The same as Table II but for assimilation of categorical forecasts. (See strategies 1.- 9. in Table IV)

Inequalities		Strategies 1.	2.	3.	4.	5.	6.	7.	8.	9.
I.	$\frac{c}{1-b} < \frac{p_1 P}{(1-p_2)(1-P)}$	Ø	Ø	Ø	+	+	+	-	-	-
II.	$a < \frac{p_1 P}{(1-p_2)(1-P)}$	+	+	+	Ø	Ø	Ø	-	-	-
III.	$\frac{a-c}{b} < \frac{p_1 P}{(1-p_2)(1-P)}$	+	+	+	-	-	-	Ø	Ø	Ø
IV.	$\frac{c}{1-b} > \frac{(1-p_1) P}{p_2(1-P)}$	Ø	+	-	+	-	Ø	-	Ø	+
V.	$a > \frac{(1-p_1) P}{p_2(1-P)}$	-	+	Ø	+	Ø	-	Ø	-	+
VI.	$\frac{a-c}{b} > \frac{(1-p_1) P}{p_2(1-P)}$	-	Ø	+	Ø	+	-	+	-	Ø

3.2 Probabilistic forecasts

If the decision-maker can get the undistorted π_1 and $\pi_2 = 1 - \pi_1$ probabilities of weather conditions X_1 and X_2 there is no need for further information about the forecast-skill ie. no preliminary test-period is necessary. The scheme for constructing the decision strategy is also simple. An operation is joined to appropriate probability intervals in order to minimize the expected value of loss.

Rules for choice of the optimum strategy is now being derived in four steps. First we demonstrate that the number of intervals with different operations can not be more than three for the optimum strategy (*Step 1*). Than the number of strategy-types containing two or three intervals (ie. assuming that the best strategy can not be the one fixed operation) is being reduced to two (*Step 2*). As the third step we demonstrate that applying the compromizing operation between the two adequate ones we do not always get a better strategy (*Step 3*). At last the optimum turning points between the intervals with different operations are being calculated (*Step 4*).

Step 1. If there at least four such intervals than at least two disjunct ones would have the same operation joined to. We intend to prove first that it can not be an optimum strategy because in any point being right in the middle of the distance between two optional points from the two intervals with same operation the application of this operation (instead of the original one) would give a better result.

Let this point in the middle have a π probability and the two other points from the disjunct intervals with equal operation have $\pi - \Delta\pi$ and $\pi + \Delta\pi$. Let us also assume that in these two points there are operations O_1 joined to while in point π we have O_c. Of course this strictly limits the generality of the proof but the way to prove the statement is completely similar for all the six possible combinations of flanking. The statement that the O_1, O_c, O_1 flanking for points $\pi - \Delta\pi, \pi, \pi + \Delta\pi$ is the optimum means that the losses for flankings O_c, O_c, O_1 and O_1, Oc, O_c are higher, ie.

$$a(\pi - \Delta\pi) < [b(\pi - \Delta\pi) + c(1 - \pi + \Delta\pi)] \qquad /11/$$

and

$$a(\pi + \Delta\pi) < [b(\pi + \Delta\pi) + c(1 - \pi - \Delta\pi)] \qquad /12/$$

Summing up these two inequations we get

$$a\,\pi < [b\,\pi + c(1 - \pi)] \qquad /13/$$

which means that putting operation O_1 instead of O_c into the point π a better strategy can be received.

In case of the other five possible combinations the terms are different on both sides of /11/ an /12/ but the $\Delta\pi$ increments disappear exactly in the same way and we get the necessary relation in point π similarly to /13/.

Principially repeating this change for all pairs of points taken from the original disjunct intervals with the same strategy we get either a new or a wider interval with the same operation. Anyhow the final result is one common interval with the same strategy containing the initial ones and the whole interregnum between them.

Step 2. So the maximum number of intervals with different operations in the optimum strategy is three which means *15* types of possible strategies so as *3* types containing one operation independently of the forecasted probability (ie. the a priori strategies), *6* types containing two and *6* types containing three operations in some sequence of forecasted probabilities. Furthermore the strategies where the natural order of O_1 and O_2 is disturbed ie. O_2 is joined to an interval with less π_2 can not be optimal and also those strategies can be excluded in which the compromizing operation is attributed to an interval with a probability higher than the interval with the adequate operation. We can aldo suppose that strategies with one fixed operation only can not be so effective than that of two or three operations joined to the appropriate intervals. In this way we can reduce the number of potentially optimal strategy types to four. These are $S_1 = (O_1, O_2)$, $S_2 = (O_1, O_c)$, $S_3 = (O_c, O_2)$ and $S_4 = (O_1, O_c, O_2)$.

However strategies S_2 and S_3 also can not be the optimum because joining O_2 to $\pi_2 = 1$ in S_2 and O_1 to $\pi_1 = 1$ in S_3 and also into their appropriate one-sided surroudings we get better strategies so that within these intervals an elementary loss greater than zero would have little probability (none in $\pi_2 = 1$ and $\pi_1 = 1$ respectively) instead of high probability of the finite non-zero loss in the compromizing operation.

Step 3. So the number of candidate-types *for being the optimum* is reduced two: $S_1 = (O_1, O_2)$ and $S_4 = (O_1, O_c, O_2)$. We demonstrate that the first type can also be optimal in the case of a possible relation between the type economical parameters. The first thing to prove is that having the best strategy of type S_1, an appropriate strategy of type S_4 can be better only if it does not join operation O_1 to any point where O_2 is the optimum in the best strategy of S_1. Surely in the opposite case in strategy S_4 we could join O_2 instead of O_1 to the sub-interval where it tâkes place in the optimum strategy of type S_1 getting a better strategy. However as it has been proven at the beginning of this point a strategy containing four intervals (ie. O_1, O_2, O_c, O_3 in our case) can not be the optimum.

Therefore we can reduce the question of optimity-condition to the following: What is the condition for the best strategy of type S_1 unable to being improved by inserting the operation O_c between the two adequate operations?

This inserted interval of O_c has to contain that point of the probability scale where the mean loss of operation O_1 is the same as of O_2. if supposing the interval with O_c devided one of the O_1 or O_2 intervals the number of intervals would be more than three and such a strategy could not be the optimum.

The average loss in the point where $L(O_1) = L(O_2)$ is

$$(1 - \pi_1)a = \pi_1 \qquad /14/$$

from where

$$\pi_1 = \frac{a}{1+a} \qquad /15/$$

using the loss-matrix of *Table Ic*. Inserting O_c into this point we get an average loss as high as

$$b\frac{1}{1+a} + c\left(1 - \frac{1}{1+a}\right) = \frac{b+ac}{1+a} \qquad /16/$$

The condition for this loss being lower than the initial one comparing the numerators of fractions in the right sides of /15/ and /16/ and deviding by a is

$$\frac{b}{a} + c < 1 \qquad /17/$$

which is not a straight consequence of the loss matrix set up in *Section 2*. So if /17/ is not fulfilled then the best strategy of type $S_1(O_1, O_2)$ can be more beneficial than any strategy of type $S_4(O_1, O_c, O_2)$.

Step 4. The turning point of the probability scale is determined by /15/ for the case if there is no better strategy in S_4. In the opposite case the optimity conditions are $L(O_1) = L(O_c)$ and $L(O_c) = L(O_2)$ concerning to the turning points (π_{1c} and π_{c2}) of the probability scale. This means

$$(1 - \pi_{1c})a = b\,\pi_{1c} + c(1 - \pi_{1c}) \qquad /18/$$

and

$$\pi_{c2} = b\,\pi_{c2} + c(1 - \pi_{c2}), \qquad /19/$$

which can easily be trandsformed to

$$\pi_{1c} = 1 - \frac{b}{a+b-c} \qquad /20/$$

$$\pi_{c2} = 1 - \frac{1-b}{1-b+c} \qquad /21/$$

Knowing the economical parameters of the decision problem one can assimilate the undistored probability forecast in the following way: Initiate operation O_1 when $\pi_1 > \pi_{1c}$, operation O_2 when $\pi_{c2} < \pi_1 < \pi_{1c}$ and operation O_2 when $\pi_1 < \pi_{c2}$.

The economical effect of the optimization by the probability forecasts depends on the frequency distribution of different (objective) output probabilities. Therefore it can not be expressed by simple subtractions as in case of categorical forecasts.

4. An example for the meteorological part of the decision-models

Formulae derived in *Sections 2* and *3* are fairly general for the decision in a concrete situation ie. in case of three possible operations influenced by two alternative weather states. In order to help in their application easier we present an example which is based on macrosynoptic types derived by *PECZELY (1957, 1983)* for Hungary. Here we arbitrarily demonstrate the case of measurable precipitation in January at Budapest applying the necessary informations from *PECZELY (1961)*. (See *Table VI*)

Table VI

The probability of precipitation [π_2 (T_i)] in different (T_i) macrosynoptic types appearing with a $p(T_i)$ probability at Budapest in January and also their product asthe weight of each macrotype in climatic probability of precipitation

Péczely-types		$\pi_2(T_i)$ %	$p(T_i)$ %	$p(T_i)\,\pi_2(T_i)$ %
T_1	CMw	78	8.8	6.9
T_2	C	75	0.7	0.5
T_3	mCw	68	8.8	6.0
T_4	zC	61	7.0	4.3
T_5	CMc	45	2.4	1.1
T_6	mCc	43	4.0	1.7
T_7	Ae	39	13.7	5.3
T_8	AF	37	4.7	1.7
T_9	As	36	7.1	2.6
T_{10}	Aw	31	11.0	3.4
T_{11}	An	30	11.6	3.5
T_{12}	A	21	16.6	3.5
T_{13}	AB	19	3.6	0.7
Total			100.0	41.2

If we have only the a priori (climatic) information that is a general probability of precipitation (being $p = 41.2$ % in our case) we can choose the most beneficial standard operation by inequalities in *Table II*. Having a categorical forecast which in this case is equivalent to a definition of a P_{cut} probability and saying "precipitation will exist" if $\pi\,(T_i) > P_{cut}$ and vice versa. In this case we need a preliminary period to establish P_1 and P_2 if we do not know this P_{cut}. But knowing the forecaster's (standard) P_{cut} we can calculate the key parameters of the forecast as

$$p_1 = \frac{\sum\limits_{\pi(T_i) < P_{cut}} p(T_i)\,(1-\pi(T_i))}{1-P} \qquad /22/$$

$$p_2 = \frac{\sum\limits_{\pi(T_i) > P_{cut}} p(T_i)\,\pi(T_i)}{P} \qquad /23/$$

In *Figure 1* these forecast-skills are presented in function of P_{cut}. We can establish that increasing or decreasing of P_{cut} we can change p_1 and p_2 in the opposite direction. The optimum P_{cut} (which is equal to $1 - \pi_1$ from /15/ for probabilistic forecasts) strongly depends on the economical parameters. Having the key parameters of the forecast-skill the choice of the optimum strategy can be further accomplished applying inequalites of *Table V*.

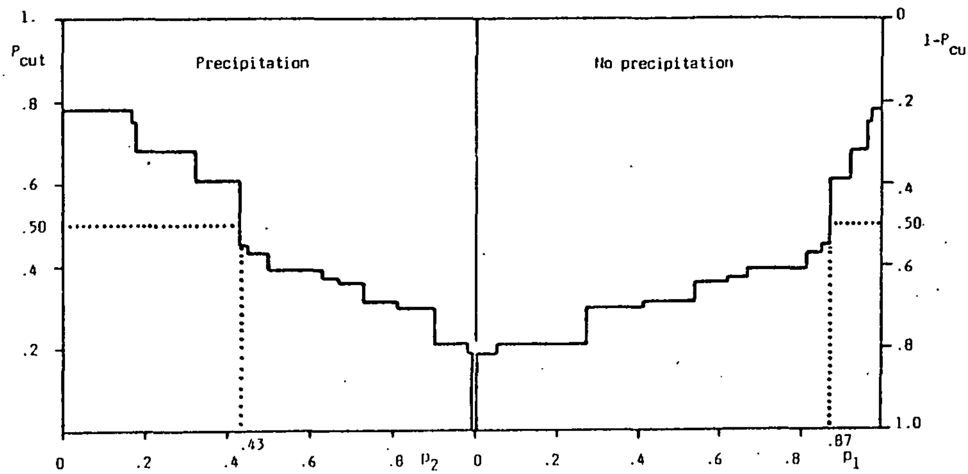


Fig. 1 The skill of two categorical statements as functions of the critical probability (P_{cut}) for saying "yes" (if $\pi_2 > P_{cut}$) or "no" ($\pi_2 < P_{cut}$). The arbitrary P_{cut} = 0.50 illustrates the asymmetry of P_1 and P_2. Here P_2 belongs to the existence of precipitation. For further information see Table IV.

In case of probabilistic forecasts the formulae /15/ or /20/ and /21/ (depending on logical value of /17/ dictate the optimum strategy while the necessary probabilities can be calculated on the base of *Table VI* by grouping the terms for which $\pi(T_i)$ are adequate to probability intervals of the different operations. In these examples we can also see that the most efficient information on weather is the probabilistic forecast which allows the application of all the three operations or if the two-operation variant is the optimum its turning points are chosen as the most beneficial. In case of categorical forecats maximum two operations can be applied as a function of forecasted staatement and its turning point of the probability scale (P_{cut}) is chosen arbitrarily by the forecasters ie. independently of the decision problem. The less beneficial tool in this context is of course the climatic probability alone which allows one single operation not applying any supplemental real-time information.

Acknowledgements

The study was partly supported by contract OTKA-1837.

References

ANDERSON,J.R. - DILLON,J.L. - HARDAKER,J.B.,1977: Agricultural decision analysis - Iowa State University Press

BELENKY,D.H. - BRAGINSKAYA,L.L. - GANDIN,L.S. - ZHUKOVSKY,E.E.,1974: On the economically optimal strategies of the use of meteorological information - *Időjárás 78*, 262-266

KAROSSY,CS.,1987: Catalogue of macrosynoptic types for Hungary (1983-1987) defined by Péczely - *Legkőr 32*, No 3, 28-30 *(In Hungarian)*

KOPPANY,G.,1975: Verification methods of weather forecasts - Studies in Meteorology No 5, Hungarian Meteorological service, 46 p *(In Hungarian)*

KOPPANY,G.1987: Climatic fluctuations in the 200 years temperature series of Budapest - *Proceedings of the X-th Czechoslovak-Hungarian Meteorological Conference*, 131-139

MIKA,J.,1982: On the verification and economical benefit of weather forecasts - *Reports on Scientific Researches Carried out in 1980*, Hungarian Meteorological Service, Budapest, 53-59 *(In Hungarian)*

MIKA,J. - BONCZ,J.,1983: Application of climatological means for estimation of the monthly mean temperature *Időjárás 87*, 206-213 *(In Hungarian)*

PECZELY,G.,1957: Grosswetterlagen in Ungarn - Kleinere Veröffentlichungen der Zentralanstalt für MMeteorologie, Budapest No 30, 86 p

PECZELY,G.,1961: Climatical characteristic of macrosynoptic types for Hungary - Short Publications of Hungarian Meteorological Institute No 32, 128 p *(In Hungarian)*

PECZELY,G.,1983: Catalogue of macrosynoptic types for Hungary (1881-1883) - Short Publications of Hungarian Meteorological Service 53, 115 p *(in Hungarian)*

ZHUKOVSKY,E.E.,1981: Meteorological information and economical decisions - Gidrometeoizdat,Leningrad,303 p *(In Russian)*

Contents